Introduction

Aims of the Physics Syllabus

This syllabus presents a modern view of physics with major emphasis placed on the fundamental concepts underlying this basic science. The syllabus is designed to encourage the utilization of such basic concepts as the conservation of energy, the conservation of momentum, the conservation of charge, vectors and scalars, and fields as unifying themes rather than as isolated topics. This approach tends to foster an appreciation for the unity of physics. As a result, the syllabus shows the importance of these ideas as unifying themes which can be applied repeatedly throughout the course.

The objectives of the course in physics should extend beyond a minimal comprehension of the basic facts and principles outlined in this syllabus. The ability and willingness to change beliefs and opinions after careful weighing of new evidence and the development of the habit of critical thinking are the most important outcomes of the study of this science. These methods of thought and action will remain long after many specific details of subject matter are forgotten.

Major scientific advances within the past forty years have created a critical shortage of skilled technicians, scientists, and engineers. At all levels of ability, there is an increasing demand for workers with more training and understanding of our physical world. Of even greater importance is the need for a continuing supply of well-informed citizens capable of making sound decisions on the many new issues and problems that face us including the efficient use of natural resources and maintenance of a healthy environment.

To deal with these complex issues and problems as adults, students must acquire scientific literacy by developing skills and positive science attitudes and by acquiring knowledge about the natural world. Students demonstrate this literacy by applying their skills, attitudes, and knowledge to solve problems appropriate for their age levels.

Problem Solving

Problem solving should be an overall theme for the entire course of study, rather than being treated as a special subject. It is an integral part of a student's learning experience and may be related to both traditional class problems and laboratory experiences. Problem solving is the application of logical and creative thinking to a new and unfamiliar situation requiring resolution. A scientifically literate person is an effective problem solver.

Before a student can solve a problem, the student must recognize that there is a problem to be solved. To help students recognize a problem, use their EXPERIENCES to make them aware of DISCREPANCIES. The discrepancies should lead them to raise QUESTIONS, and the questions will help them to define the problem.

EXPERIENCES can be both spontaneous events and teacher-planned activities. The experiences chosen for instruction should be ones that make students aware of discrepancies.

DISCREPANCIES are differences, inconsistencies, disagreements, or disharmonies that we encounter. A discrepancy becomes evident only when we have some prior experience or basis for comparison.

Types of discrepancies	Examples
• A goal to achieve without a means to achieve it.	• A person needs to zero an ammeter, but the adjustment screw is missing.
• A difference between what the student expects to observe and what the student actually does observe.	• A rubber ball does not bounce.
• A lack of knowledge – others may know the information, but the student does not.	• Astronauts experiencing weightlessness when orbiting the Earth are undergoing an acceleration.
• A difference between what the student has been told is true and what the student has already verified personally.	• A student is told that heavy objects and light objects will hit the ground at the same time.
• A conflict (internal or external) between interpretations, opinions, attitudes or values.	• Students participate in a debate of the pros and cons of building a nuclear energy plant.
• A difference between an existing set of conditions (what is) and a desired set of conditions (what should be).	• Many people do not wear seat belts while riding in a car.

QUESTIONS play a vital role in problem solving because they help to identify and define the problem and to guide the systematic search for a solution. Once a student recognizes a discrepancy, encourage the student to construct many questions about it. It is important that students are taught to construct precise questions (who?, what?, when?, where?, which?, why?, how?, what if?). When a student has constructed a precise question, the student has more clearly identified the problem.

Once a student has identified the problem by constructing precise questions, the student can proceed with problem solving. One model for problem-solving consists of a sequence of steps, beginning with planning and progressing to decision making. For each step in the sequence, the problem solver will:

- construct questions;
- identify, select, and apply skills; and
- create tangible products which contain answers to the questions.

Refer to the problem-solving model in Appendix A. Although this is organized into a sequence of steps that have a logical progression, it is important to note that, in practice, problem solvers often move back-and-forth among the steps as a problem is worked. For example, a need to reorganize the data may not become apparent until the data are analyzed. As the data are being analyzed, a problem solver may realize that additional data must be obtained. Appendix A contains additional information about problem-solving, and examples of physics problems.

Skills

Skills are the tools needed to solve problems. A student needs to learn the appropriate use of each skill and needs sufficient opportunity to apply each skill in realistic situations. The skills which students should develop during a course in physics include:

- Applying Mathematics
- Classifying
- Communicating
- Creating Models
- Formulating Hypotheses
- Generalizing
- Identifying Variables
- Inferring
- Interpreting Data
- Identifying/Selecting Alternatives
- Manipulating Materials
- Measuring
- Observing
- Predicting
- Recording Data
- Verifying

Descriptions and examples for each of these skills are found in Appendix B. These skills are subject to testing on the Regents *Examination in Physics*. Skills specific to the laboratory will be discussed in the section on the *Laboratory*.

Attitudes

Students can increase their capacity to appreciate nature and enjoy the process of studying about it. This is the most encompassing positive science attitude for students to develop. This attitude can be nurtured by helping students develop more specific positive science attitudes about:

- the natural world
- the nature of science
- the application of skills and knowledge to solve problems for the benefit of others

Specific examples of positive attitudes are listed in Appendix C.

Applications

It is both easy and valuable to show the role of physics principles in common experiences. Since transfer of learning is only likely to occur when specifically taught, applying physical concepts to students' experiences will help them develop confidence in their ability to understand and deal with other aspects of the physical world. As a result, students will be better prepared to make the evaluative judgments that a democratic society requires of its citizens. Practical applications, suggested throughout the syllabus, provide motivation for students as they begin to perceive physics as a familiar and enjoyable subject.

Sequence and Scheduling

One of the major challenges in constructing a syllabus for a one-year course in physics is to provide a general understanding of the fundamental principles of physics and, at the same time, to achieve a deeper understanding of some of these principles. There is insufficient time in a one-year course to teach all the physics the teacher may wish to teach. Choices must be made.

In an attempt to provide some degree of flexibility in the course, and at the same time insure adequate coverage of basic areas, the content outlined by the syllabus has been limited to a basic core, comprised of five units, and six optional areas. The *minimum requirements* for a course based on this syllabus include the basic core and *two* of the six optional areas.

The minimum time required for a course based on this syllabus is the equivalent of six 40-minute periods per week, although seven periods are recommended. This time allotment should include at least one double laboratory period each week.

The core units are listed as units I through V to avoid confusion with the optional units VI through XI. The order of presentation used in the syllabus indicates one of several possible teaching sequences. Any sequence that presents a logical development of physical principles may be followed. For example, if the optional unit **Motion in a Plane** is to be taught, the topics in this area may be incorporated into the **Mechanics** unit.

Teachers are encouraged to set their own time allotments based on their teaching experience and on student interest and achievement. Below is a suggested time frame based on the idea that this syllabus represents a survey course in physics in which many topics should be given equal treatment.

Mechanics – 9 weeks
Energy – 3 weeks
Electricity and Magnetism – 8 weeks
Wave Phenomena – 7 weeks
Modern Physics – 2 weeks

Each Optional Area – 2 weeks

Organization of the Syllabus

The syllabus is divided into the five core units and six optional units. The core units are:

Mechanics
Energy
Electricity and Magnetism
Wave Phenomena
Modern Physics

The optional units are:

Motion in a Plane
Internal Energy
Electromagnetic Applications
Geometric Optics
Solid State Physics
Nuclear Energy

The syllabus is organized under three major headings in three columns.

1. **Content Outline/Understandings/Concepts**

   This column contains the topical outline and basic concepts of the course and lists quantitative requirements. Concepts in this column are subject to testing on parts I and III, if core, or part II, if optional, of the Regents examination. The asterisk (*) used in the outline denotes that quantitative treatment is required.

2. **Discrepancies/Practical Applications/Activities**

   This column contains discrepancies in italics and practical applications and gives additional information including Unifying Themes, special activities related to the development of skills, and requirements for a course based on this syllabus. Material contained in this column is subject to testing on parts I and III, if core, or part II, if optional, of the Regents examination.

   Discrepancies and practical applications do not have to be memorized by students, but references to them and questions about them may appear on the Regents examination.

3. **Supplementary Information**

   This column includes additional information and explanation of the basic concepts. The material in this column is *not* subject to testing.

Prerequisites

Students enrolling in the Regents physics course must have satisfactorily completed sequential mathematics Course I. They should have also completed or at least be currently enrolled in sequential mathematics Course II. Application of mathematical skills is stressed frequently in this syllabus. Some of this material will already have been developed in courses in mathematics and science. Other topics, such as vectors, may not have been previously studied. **Teachers are encouraged to review mathematical skills and present new mathematical concepts when introducing the associated physics material, rather than spending the first week or two in math review.** For more information, see Appendix E, Mathematics and Measurement.

Systems of Units

SI (International System) units are used in this syllabus. The fundamental units used are the meter, kilogram, second, ampere, and Kelvin. The fundamental units candela and mole are not used in this syllabus.

Regents examination questions will be in terms of the five fundamental units mentioned above and the appropriate derived units (e.g. newton, joule, volt, etc.) as defined at appropriate points in the syllabus. The only exceptions to this rule are the electronvolt, which is a widely used unit of energy, and the atomic mass unit. While examination questions will be confined to these units, the use of other systems (e.g. CGS and FPS) in class and in the laboratory is encouraged.

Significant Figures and Precision in Measurement

The concept of significant figures is important for precision in measurement, but is difficult for many high school students. It is left to the teacher to determine the depth to which the topic is appropriate for his/her particular students.

Students are expected to understand significant figures in terms of the degree of precision to which a common measuring device can be used. This is subject to testing. See Appendix E, Measurement and Mathematics, for examples of the types of questions a student may be asked on the Regents physics examination. Performing operations with significant figures is not subject to testing.

The Regents Physics Examination

The Regents *Examination in Physics* has three parts. Part I consists of 60 multiple-choice questions based only on the core, units I through V, and accounts for 70% of the total score on the examination. Part II consists of six groups of 10 multiple-choice questions. Each group is based on one of the optional areas, units VI through XI. Students will choose two of the six optional areas in part II, which accounts for 20% of the total score. Part III consists of free-response questions based on the core, units I through V, and accounts for 10% of the total score. For information about free-response questions, see Appendix D.

All students must be provided with a centimeter ruler and a protractor for the Regents examination. Students may use calculators for the examination provided all students in the physics class have access to a calculator during the examination.

Laboratory

The pragmatic approach of "learning by doing" is inherent in a physics course using the laboratory investigations approach. The knowledge obtained by students from meaningful manipulation of laboratory materials can have a profound effect upon their lives by increasing their awareness of the environment of which they are a part. The importance of laboratory work is highlighted by the need to:

1. Stimulate the development of basic skills by providing experiences in recording and interpreting data and manipulating equipment.
2. Develop safety habits which are transferable to everyday situations in and out of school.
3. Provide first-hand experiences with some of the ways in which scientists collect, organize, and interpret data under controlled conditions.
4. Provide some first-hand experiences using activities which are associated with a variety of science-related careers.
5. Stimulate and maintain student interest while developing and reinforcing understandings basic to the course.
6. Foster the attitude that physics is learnable and applicable to the lives of students.

The laboratory can be defined as the place where physics students engage in the manipulation of concrete objects. Manipulative activities provide direct experiences for the students and enable them to answer important questions on the basis of personal observation and experimentation. When planning laboratory experiences, priority should be given to field and laboratory activities which feature manipulation. On rare occasions, there are legitimate instances when nonmanipulative activities can and probably should be substituted for these hands-on activities. The less direct experiences available through filmloops, videotapes, videodiscs, photographs, teacher demonstrations, and microcomputer simulations can be reasonably substituted when the objects or energy levels are sufficiently hazardous, the activity is excessively costly, or the equipment is inaccessible. These situations represent the exception, and should comprise no more than 15% (4.5 periods) of the minimum laboratory requirement of thirty 40-minute periods.

Laboratory investigations should take many forms. In addition to exercises which simply require verification of known constants or relationships using an established procedure, students should also be encouraged to design their own method for a particular investigation and to determine which variables affect the results. In some cases, teachers will find it appropriate for a laboratory experience to precede classroom discussion, while on other occasions laboratory work can be used as an effective follow-up activity. It is vital that laboratory and class work be carefully integrated. Furthermore, teachers are encouraged to provide students with numerous opportunities for hands-on activities, not only during the laboratory, but throughout the physics course.

Regents physics has a mandated laboratory requirement, and successful completion of this course earns for the students one unit of credit in a laboratory science. Each student must be engaged in laboratory activities for at least thirty 40-minute periods (or its equivalent of 1200 minutes) exclusive of time used in changing classes or teachers. Satisfactory written reports of these laboratory experiences must be prepared by the student. Standards for satisfactory written reports must be established by the local school district at the beginning of the school year. At the completion of the course, these laboratory reports must be kept in the school for six months following the date of the examination, except in instances where a senior or transferring student needs these reports for further work.

Pursuant to Section 207 of the Education Law, Section 8.2(c) of the Rules of the Board of Regents states, "Only those persons who have satisfactorily met the laboratory requirements as stated in the State syllabus for a science shall be admitted to the Regents examination in such science." This Rule of the Board of Regents applies to all students whether regularly enrolled in a Regents science class or studying independently. For students with severe physical or emotional handicaps, admission to a Regents science examination without having completed the laboratory requirement will be considered on an individual basis. Questions pertaining to this matter should be directed to the Chief of the Bureau of Science Education, State Education Department, Albany, New York 12234.

The emphasis placed on the laboratory component of this course requires that the teacher be able to evaluate student competencies in the laboratory. In addition to the skills listed above and described in Appendix B, students are required to demonstrate competency in seven manipulative skills:

1. Demonstrate safety skills involved in handling equipment such as projectiles, chemicals, heating elements, electrical circuits, and radioactive materials.
2. Determine the change in length of a spring as a function of force. Graph the data.
3. Determine the period of a pendulum for a given mass and a given length.
4. Set up a series circuit and a parallel circuit each consisting of a source of potential (battery, power supply) and two resistances (light bulbs, resistors). Determine the current through and potential difference across each resistance and the circuit as a whole.
5. Map a magnetic field using a magnetic compass and a permanent magnet or electromagnet.
6. Determine the path of a light ray passing from air through another medium and back into air using a transparent object (rectangular block, semicircular container). Draw the ray diagram.
7. Formulate inferences about the contents of a "black box" (a sealed system into which one cannot see) by making external observations. Examples of "black boxes" include:
   a) Light rays entering and emerging from a box containing unknown optical components. Students identify the instruments by observing the path of the light rays entering and leaving the box.
   b) A shoe box containing objects having different properties (i.e., magnetic, scent, etc.). Students identify the contents through the use of appropriate tools (i.e., compass, nose, etc.).

   "Black boxes" enable students to understand the process of modeling more clearly, especially as it relates to the development of the model of the atom. An exciting activity is to have the students design the "black boxes."

The Evaluation Plan for assessing proficiency in these seven skills consists of these two components:

1. written responses on the Regents examination, and
2. laboratory performance in the local school setting.

The seven manipulative skills are best assessed by the teacher observing students in the local school setting. **It is the responsibility of the teacher to determine that these skills have been demonstrated.** A Physics Laboratory Skill Evaluation form is included in Appendix B. As each skill is satisfactorily completed, the date and the initials of both the teacher and student are to be recorded on the evaluation form. Satisfactory completion of all seven skills is required prior to admittance to the Regents examination. These completed forms must be filed with the student's written record of laboratory work for a period of six months after the completion of the course.

Safety Suggestions

1. Students should not handle chemicals or equipment in the laboratory until they have been given specific instructions.
2. Students should report at once any equipment in the laboratory that appears to be unusual such as broken, cracked, or jagged apparatus, or any reactions that appear to be proceeding in an abnormal fashion.
3. Students should report any personal injury or damage to clothing to the teacher immediately no matter how trivial it may appear.
4. Loose clothing and hair should be prevented from coming in contact with any science apparatus, chemicals, or sources of heat or flame.
5. Laboratory materials should not be transported through hallways by unsupervised students or during the passing of classes.
6. Students should be instructed never to taste, or inhale directly, unknown chemicals.
7. Students should be warned of the dangers involved in the handling of hot glassware or other equipment. Proper devices for handling these items should be available.
8. Electrical wiring should be checked for fraying, exposed wires, and loose connections.
9. Students should be familiar with the location and use of the fire blanket, fire extinguisher, and eye baths.
10. Students should wear safety glasses whenever chemical or projectile labs are being performed.
11. Students should be given instructions on the proper use of electrical equipment.
12. Appropriate, specific safety instructions should be given which are applicable to particular experiments.

Changes in the Syllabus

Corrections or changes in the syllabus that become necessary will be brought to the attention of school principals by means of supervisory letters from the Department.

Unit One

MECHANICS

Content Outline/ Understandings/ Concepts	Discrepancies/ Practical Applications/ Activities	Supplementary Information
I. KINEMATICS Kinematics deals with the mathematical methods of describing motion without regard to the forces which produce it. The motion of a body may be described in terms of its position as a function of time.	Unifying theme: Vectors Requirements are limited to motion with constant acceleration in a linear path. Practical applications: • bicycles • skateboards • roller skates • cars • toys	Motion is relative to a frame of reference. Whenever quantities are introduced their vector or scalar nature should be stressed.
***A. Distance and displacement** Distance is a scalar quantity that represents the length of a path from one point to another. Displacement is a vector quantity that represents the length and direction of a straight line path from one point to another. Total displacement is a vector sum.	Quantitative requirements include graphical solutions for displacements at any angle and numerical solutions limited to two displacements at angles of 0°, 90°, and 180°. Practical applications: • displacement (air distance) vs. road distance between two cities • map reading • odometer reading on a car	A jogger is concerned with distance; a pilot, with displacement.
B. The meter The meter, m, is the SI unit of length. It is a fundamental unit.	The length of a meter should be made familiar to students in terms of their own bodies and other familiar lengths.	The concept of fundamental units should be introduced. As units are introduced they should be classified as fundamental or derived. One meter is the distance light travels in a vacuum in 1/299,792,458 second.
***C. Velocity and speed** Velocity is a vector quantity which represents the time-rate of change in displacement for an object. Speed is a scalar quantity which represents the magnitude of the velocity. The slope of a position-time curve is the time rate of change of position (speed). $\bar{v} = \frac{s_f - s_i}{t_f - t_i} = \frac{\Delta s}{\Delta t}$	*Two cars moving at 88 km/h in opposite directions have different velocities.* Quantitative requirements include the ability to recognize, interpret, and use graphs of displacement versus time and to apply the related equations. Practical applications: • fastball thrown at 150 km/h • speed limit • reading on a car's speedometer	The relation of position as a function of time should be developed graphically. The time, whether dependent or independent, should be plotted on the horizontal axis. Slopes very often have physical meaning that can be best shown in graphic form. The reading on a car's speedometer is instantaneous speed. Ticker-tape timers provide students with

Content Outline/ Understandings/ Concepts	Discrepancies/ Practical Applications/ Activities	Supplementary Information
		an observable pattern by which to compare constant velocity with acceleration.
If the speed is changing, the distance-time graph is curved, and the slope of the tangent to the distance-time curve at any point represents the instantaneous speed at that point.		
The second, s, is the SI unit of time. It is a fundamental unit. The meter/second, m/s, is the SI unit for velocity.	Practical applications: • pendulum clock • stop watch Students are required to determine the period of a pendulum. The size of a second should be made familiar to students in terms of their pulse-rate and by counting "one-thousand-one, etc."	One second is the time for 9,192,631,770 cycles of the electromagnetic radiation which will cause transitions between the two lowest energy states of the cesium-133 atom. Find the length of a pendulum that has a period of one second.
***D. Acceleration**		
Acceleration is a vector quantity that represents the time-rate of change in velocity of an object. The meter/second squared, m/s^2, is the SI unit for acceleration. The slope of the speed-time graph is the time rate of change in velocity (acceleration). $\bar{a} = \frac{v_f - v_i}{t_f - t_i} = \frac{\Delta v}{\Delta t}$	*It takes approximately 8.5 minutes to reach orbital velocity from an at-rest position on the launch pad.* Quantitative requirements include the ability to recognize and interpret graphs of velocity versus time, and to apply related equations. Practical applications: • automobile • jet plane	The relation of velocity as a function of time should be developed graphically. Using data taken from a videotape of a space shuttle launch, calculate acceleration. The area under the velocity-time curve represents displacement.
***E. Final velocity of and distance traveled by an object at constant acceleration.**		
The final velocity and the distance traveled by an object at constant acceleration are functions of the initial velocity, acceleration, and time. $s = v_i \Delta t + \frac{1}{2} a (\Delta t)^2$ $v_f^2 = 2a \Delta s + v_i^2$ The average velocity of a uniformly accelerated object may be found by averaging the initial and final velocities. $\bar{v} = \frac{v_f + v_i}{2}$	Practical applications: • stopping at a red light • tailgating the car ahead Requirements include problems in which $v_i \neq 0$.	It should be stressed that the speed of an object with constant acceleration changes at a constant rate. Derive the equations $s = v_i \Delta t + \frac{1}{2} a (\Delta t)^2$ and $v_f^2 = 2 a \Delta s + v_i^2$ These relationships are valid only for cases where there is a constant acceleration.
***F. Freely falling objects**		
Objects freely falling for short distances may be considered as examples of objects with constant acceleration.	*The acceleration of a freely falling object near the surface of the earth is 9.8 m/s^2.* Quantitative requirements for free fall	The limits imposed by air friction and terminal velocity should be discussed. "Short distances" can be considered to

Content Outline/ Understandings/ Concepts	Discrepancies/ Practical Applications/ Activities	Supplementary Information
An object in free fall is considered to have no appreciable air resistance acting on it.	problems are limited to solving problems with constant acceleration, no friction, and with initial or final velocity equal to zero. Practical applications: • free fall type amusement park rides • sky diver	be from sea level where g = 9.806 m/s² to an altitude of 16 km where g = 9.757 m/s². To improve students' ability to estimate answers, approximate g as 10 m/s². If the optional unit "Motion in a Plane" is to be covered, trajectories may be taught here.

+ Projectile Motion 6, I

II. STATICS

Statics deals with the relation between forces acting on an object at rest.

Unifying themes: Vectors, Fields

A. Force

Content Outline/ Understandings/ Concepts	Discrepancies/ Practical Applications/ Activities	Supplementary Information
A force is a vector quantity.	*A wall can push.* Practical applications: • weight. Use spring scales calibrated in newtons to give students some concept of the size of a newton.	A more rigorous definition of force will be developed in considering Newton's second law of motion. The region in which a force acts is known as the "field" of the force. The field concept may be introduced when the concept of a gravitational field is developed. The unit of force, the newton (N), will be introduced when Newton's second law is discussed. 1 N = 3.5 OZ = .22 lb. A medium sized apple weighs about 1 N. Interactions may be classified as: 1) strong interactions (the strongest) 2) electromagnetic interactions 3) weak interactions 4) gravitational interactions (the weakest). There is some debate as to whether the weak interaction should be referred to as a force.

*B. Vector addition of concurrent forces

The resultant of two or more concurrent forces acting on a body is the single force producing the same effect. The resultant may be found by the vector addition of the individual forces.

The net force acting on a body is the vector sum of all concurrent forces acting on the body.

If the angle between the forces is 0°, the resultant force is a maximum. If the angle between the forces is 180°, the resultant force is a minimum.

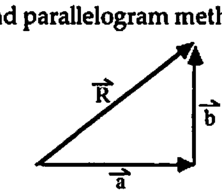
A 50 kg girl can outpull two 90 kg football linemen.

Quantitative requirements include graphical solutions limited to two forces acting at any angle and numerical solutions limited to forces acting at angles of 0°, 90°, or 180°.

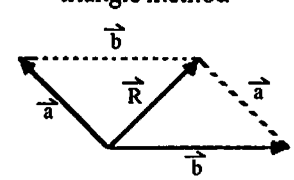
Practical applications:

- sitting in a chair
- a hanging sign

Graphical solutions include using the triangle and parallelogram methods.



triangle method



parallelogram method

Content Outline/ Understandings/ Concepts

Discrepancies/ Practical Applications/ Activities

Supplementary Information

It may be necessary to review the pythagorean theorem, basic trigonometric functions, and the use of the protractor.

Concurrent forces act on the same point of a body.

***C. Resolution of forces**

A single force may be resolved into an unlimited number of components.

The vector sum of the components is equal to the force.

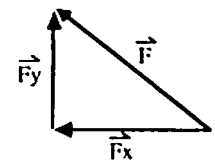
Quantitative requirements include graphical solutions limited to components at right angles to each other and the resolution of forces into x and y components.

Resolve the forces acting on a box resting on an inclined plane into the parallel and perpendicular components of the force.

Practical applications:

- pushing a lawnmower
- pulling a wagon

Resolution of forces into x and y components provides a convenient method for solving vector problems. For example:



***D. Equilibrium**

If the vector sum of the concurrent forces acting on an object is zero, the object is in equilibrium.

Identify situations in which the net force is zero and an object is in equilibrium.

Experiments with force tables clearly illustrate equilibrium.

The equilibrant is the force that is equal and opposite to the resultant.

An object in static equilibrium remains at rest or moves with constant velocity.

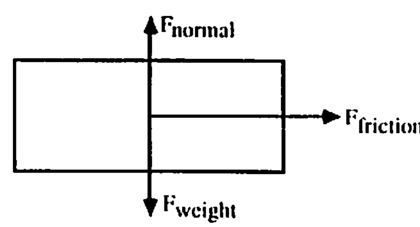
Draw a free-body diagram showing the forces on a suspended cart that appears to be resting on an inclined plane. Remove the plane and the cart stays in place.

Practical applications:

- a car moving at 88 km/h
- sitting in a chair

Free-body diagrams show all the forces acting on a body. For example:

- a box sliding to the left



III. DYNAMICS

Dynamics deals with the relation between the forces acting on an object and the resulting motion.

A. Force, mass and acceleration; gravitational and inertial properties of objects

1. First law of motion

An object remains at rest or moves with constant velocity unless acted upon by an unbalanced force.

The first law of motion is called the law of inertia.

The inertia of an object is proportional to the object's mass.

A space probe continues moving after the engines are shut off.

Draw free-body diagrams.

Practical applications:

- seat belt
- pulling a tablecloth out from under dishes

The first law defines Newtonian frames. If such a frame is assumed, the first law may be presented as a special case of the second law, where the net force is zero. An example of a non-Newtonian frame might be an accelerating car in which an object on the dash is observed to slide with respect to the non-Newtonian

Content Outline/ Understandings/ Concepts	Discrepancies/ Practical Applications/ Activities	Supplementary Information
	• tossing and catching a ball on a moving train • tightening a loose hammer head	frame of the accelerating car without any force pushing it.
*2. Second law of motion An unbalanced force (net force) acting on an object causes an acceleration which is directly proportional to the force and in the direction of the force. $F = ma$ The slope of a force vs. acceleration graph is the mass of the object. The unbalanced force (net force) is the vector sum of all the forces acting on the object.	Practical applications: • elevator • stepping off a chair	Stress that in the equation $F = ma$, F is a net force. Have students stand on a bathroom scale as they ride up and down in an elevator. Discuss the changes in weight reading as the elevator begins to move upward or begins to move downward.
a. The kilogram The kilogram, kg, is the SI unit of mass. It is a fundamental unit.		The kilogram is the mass of a specific platinum-iridium alloy cylinder kept at the International Bureau of Weights and Measure at Sevres, France. It is the only standard based on a physical artifact.
b. The newton The newton, N, is the SI unit of force. The newton is the amount of force which will impart to a mass of one kilogram an acceleration of one meter per second squared. It is a derived unit. $1 \text{ newton} = \frac{1 \text{ kilogram} \cdot \text{meter}}{\text{second}^2}$		One kilogram weighs 9.8 newtons at short distances above the surface of the Earth. Stress the difference between mass and weight.
* Uniform Circular Motion - 6, IV *3. Newton's Universal Law of Gravitation Any two point masses attract each other with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. $F = G\frac{m_1 m_2}{r^2}$ Every mass may be considered to be surrounded by a gravitational field. The interaction of an object with the field produced by another object results in the attraction.	The value for the universal gravitational constant is $6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2$. Unifying theme: Fields Practical applications: • moon orbiting the Earth • tides	The relationship between gravitational force and distance is the first example of the inverse square law to be encountered. Since this law applies to many fields, an understanding of it at this point is desirable. The limitation of the gravitational law to point or spherical sources with uniform mass distribution should be emphasized. The concept of field was introduced by Michael Faraday to deal with the problem of forces acting at a distance. Develop the "field" concept as applied to the gravitational field associated with a mass. The masses referred to relate to the property of mutual attraction of matter and not to the property of inertia. Mass measured by gravitational attraction is
* Keplers Laws 6, III * Satellite Motion 6, IV		

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called gravitational mass. The most sensitive experiments possible to date conclude that gravitational mass is numerically equal to inertial mass, and both are expressed in the same units.

*4. Gravitational field strength

The magnitude of the strength of a gravitational field at any point is the force per unit mass at that point in the gravitational field.

$$g = \frac{F}{m}$$

The gravitational field strength, g, is also referred to as the acceleration due to gravity.

$$\frac{1 \text{ meter}}{\text{second}^2} = \frac{1 \text{ newton}}{\text{kilogram}}$$

The force to mass ratio is the same for all objects for short distances above the surface of the Earth.

The field is a vector quantity.

An object can push or pull you without touching you.

Unifying themes: Fields, Vectors

Practical applications:

- solar system

The acceleration due to gravity is commonly denoted by the symbol g.

Demonstrate that g is the same on a feather and coin dropped in an evacuated tube (guinea and feather tube).

Apollo astronauts in 1971 dropped a feather and hammer on the moon to show that they fall at the same rate.

The direction of the gravitational field is the direction of the force on a test mass.

*5. Weight

The weight of an object is equal to the net gravitational force acting on it.

$$w = mg$$

The weight of an object is equal to the product of its mass and the gravitational acceleration.

Weight is a vector quantity.

The magnitude of the gravitational force varies with the location of the object with reference to the Earth. The weight of an object varies with its position.

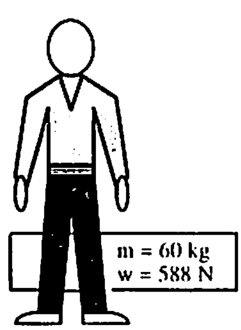
The slope of a weight vs. mass graph is g.

A person weighs less at the top of a mountain than at sea level.

As an elevator begins to rise, an object in the elevator weighs more.

Unifying theme: Vectors

In a gravitational field, g, an object of mass, m, will experience a force (weight), F = ma. If that force is the only force acting on an object, it will be accelerated according to Newton's second law: F = ma. Hence, a will equal g.



The acceleration due to gravity is a constant at any one location, and is the ratio of an object's weight to its mass. The gravitational field of the Earth at any one point has the same numerical value as the acceleration due to gravity at that point. The gravitational field strength is usually expressed in newtons/kilogram.

Spring scales graduated in newtons may be used in weight measurements, but comparison of masses ("weighing") on a balance should be referred to as measurement of mass. To one significant figure, 100 grams weigh 1 newton, 200 grams weigh 2 newtons, and so forth.

The kg and g are commonly misused as weight units. Refer to the pound and gram labels on food packages.

If the optional unit "Motion in a Plane" is to be discussed, circular motion and Kepler's Laws may be taught here.

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6. Friction Friction, which opposes motion, is the result of contact between surfaces. The normal force is the force perpendicular to the surfaces which holds the surfaces together. On a horizontal surface, the magnitude of the normal force equals the weight of the object.	*A fluid is used to reduce friction in a human joint.* Unifying themes: Vectors, Conservation of energy Practical applications: • traction on dry, wet, and icy roads • amusement park rides	Give examples where the frictional force is increased, such as putting sand on icy highways and rubbing rosin on the fingers when throwing a baseball. Give examples where the frictional force is decreased, such as waxing skis or coating a frying pan with Teflon. Demonstrate ways to decrease the friction force by lubricating surfaces or rolling one object over another.
a. The coefficient of friction The coefficient of friction is defined as the frictional force divided by the normal force.	Quantitative treatment of this relationship is not required, but students are required to use the coefficients of friction to compare the behavior of objects in motion. *Even though automobiles are constructed of metal parts with very fine tolerances, lubrication is necessary.*	
b. Static friction When an object is at rest on a surface and a force is exerted tending to slide it, the object will not move until the force exceeds the maximum static friction force. Starting friction is the maximum static friction force. Static friction is equal to the force parallel to the surfaces until the maximum static friction force (starting friction) is equalled.	Practical applications: • rotor-type amusement park ride • standing	Static friction is greater than kinetic friction because of microscopic projections on a surface. Surfaces at rest are more resistant to motion because of bonding between these projections.
c. Kinetic friction Kinetic or sliding friction is the friction that occurs when objects slide with respect to each other. Kinetic friction is less than starting friction and for non-deformable objects is practically independent of the apparent surface area and the relative velocity of the object.	*Two pieces of very smooth glass experience high sliding friction when slid across each other.* Practical applications: • toboggan • pushing a crate across the floor • sandpaper • walking	Slide a block along its different sides and measure the force needed to keep it moving at a constant velocity each time.
d. Rolling friction Rolling friction is the friction that occurs when one object is rolled over another. Rolling friction is generally less than sliding friction.	Practical applications: • automobile • roller skates • ball bearings • bicycle	To build the pyramids, the Egyptians pulled large blocks of rock over logs.

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e. Fluid friction

Fluid friction is the friction that results from an object moving through a fluid such as water or air.

Practical applications:

- parachute
- terminal velocity
- automobile
- airplane
- boat

Cars are streamlined to reduce fluid friction.

Hovercrafts ride on a layer of air which results in less friction than if the craft moved through the water.

*B. Momentum

The magnitude of the momentum of an object is equal to the product of its mass and velocity.

$$p = mv$$

Momentum is a vector quantity and has the same direction as the object's velocity.

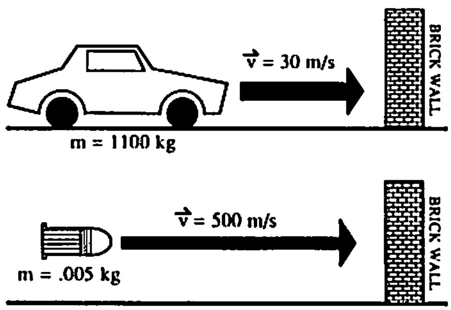
The kilogram·meter/second, kg·m/s, is the SI unit for momentum.

An automobile moving at 30 m/s has more momentum than a bullet moving at 500 m/s.

Unifying themes: Conservation of energy, Vectors

Practical applications:

- bullet penetrating a wall
- moving car



*1. Impulse

The magnitude of impulse is equal to the product of the unbalanced force acting on an object and the time the force acts.

Impulse is a vector quantity and has the same direction as the force acting on the object.

$$J = F\Delta t$$

The Newton·second, N·s, is the SI unit for impulse.

Modern uni-body cars are designed to collapse in an accident.

Practical applications:

- hitting a ball with a bat
- follow through in golf or baseball
- pushing a swing

Design landing platforms onto which raw eggs can be dropped without breaking.

From Newton's second law,

$F = ma$ or

$$F = \frac{m\Delta v}{\Delta t} \text{ and}$$

$$F\Delta t = m\Delta v$$

*2. Change of momentum

When an unbalanced force acts on an object, there is a change of momentum.

$$F\Delta t = m\Delta v$$

Quantitative requirements are limited to changes in velocity and to situations in which the impulse and momentum are colinear.

Practical applications:

- automobile collision protection
- padded baseball glove
- landing with bent, not stiff, knees

Point out that rocket propulsion involves a change in mass as the fuel is used up.

*3. Law of conservation of momentum

When no resultant external force acts on a system, the total momentum of the system remains unchanged.

When two bodies interact with no external forces, their total momentum remains unchanged.

Quantitative requirements are limited to situations in which the initial momentum in the system is zero, such as simple recoil or explosion problems.

Practical applications:

- rowing a boat
- rifle recoil
- reverse thrust of a jet engine

Graphical solution of conservation of momentum problems is *not* required. If such problems are included it is suggested they be considered after a study of kinetic energy.

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4. Third law of motion If one object exerts a force on a second, the second exerts a force on the first that is equal in magnitude and opposite in direction. The third law of motion is referred to as action-reaction.	Practical applications: • launching a space shuttle • air boat • manned maneuvering unit	The law of conservation of momentum for an isolated two-particle system is the basis for the third law of motion. Since the total momentum in an isolated two-particle system remains constant, the forces act for the same time period and are equal in magnitude and opposite in direction. Every action-reaction pair of forces involves two objects, each exerting a force on the other. Even though the forces are equal in magnitude, they produce different effects since they act on different objects.

Unit Two

ENERGY

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I. WORK AND ENERGY		
When work is done on or by a system the total energy of the system is changed. Energy is needed to do the work.	Unifying themes: Conservation of Energy, Fields Although this unit deals primarily with the concepts of mechanical energy, there are other forms of energy such as thermal, chemical, nuclear, sound and electromagnetic. Energy can be transformed from one form to another.	Since an important part of physics is a study of energy, its forms and its transformations, introduce, at this time, the general concept of energy and its various forms.
***A. Work** Work is done on an object when a force displaces the object. Work is equal to the product of the force acting on an object and its resultant displacement in the direction of the force. $W = F \Delta s$ Work is a scalar quantity.	*It is less work for a short person to lift 1400 N overhead than for a tall person.* Practical applications: • an elevator • block and tackle • jack lifting a car Quantitative requirements are limited to situations in which the force and the displacement are in the same direction.	The concept of the vector dot product applies for cases in which the force and the displacement are not in the same direction, $W = F s \cos \theta$. Force versus displacement graphs of different shapes representing various kinds of forces may be presented and interpreted. Fundamental units and dimensional analysis should be stressed.
1. The joule One joule of work equals a force of one newton exerted through a distance of one meter. The joule, J, is the SI unit of work and is a derived unit. 1 joule = 1 newton·meter $1 \text{ joule} = \frac{1 \text{ kilogram} \cdot \text{meter}^2}{\text{second}^2}$	The students should become familiar with the size of the joule by calculating the work required for simple actions, such as raising a textbook 10 cm.	One joule of work can be demonstrated by lifting an apple (mass 100 grams) through a displacement of one meter, a small amount of work in human terms.
***B. Power** Power is the time-rate of doing work. It is a scalar quantity. One watt of power equals one joule of work done in one second of time. $P = \frac{W}{\Delta t} = \frac{F \Delta s}{\Delta t} = F \bar{v}$ The watt, W, is the SI unit of power. It is a derived unit. 1 watt = 1 joule/second	Minimum quantitative requirements are limited to situations where work is done at a steady rate. Practical applications: • running up the stairs • horsepower rating of a car engine	The concept of instantaneous power using work-time graphs which are not linear may be introduced. The expression, $F \Delta s / \Delta t$, also represents average power generated when the speed of the object to which the force is applied varies with time. Power is the slope of a work versus time graph.

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$$1 \text{ watt} = \frac{1 \text{ kilogram} \cdot \text{meter}^2}{\text{second}^3}$$

In human terms, the watt is a small unit of power. For this reason, power is often expressed in kilowatts.

C. Energy

There are various forms of energy.

The same units are used to measure work and energy. Work can be done only by the transfer of energy from one object or system to another.

The joule, J, is the SI unit of energy.

Energy is a scalar quantity.

1 joule = 1 watt·second

A power company really sells energy.

Practical applications:

- electrical energy
- mechanical energy
- heat
- solar energy
- wind energy

One horsepower = 746 watts

The kilowatt-hour should be discussed as a unit of energy.

1 kilowatt-hour = 3.6×10^6 joules

1. Potential energy

Potential energy is the energy an object has because of its position or condition. The change in potential energy is equal to the work required to bring the object to that position or condition from its original position or condition assuming no energy lost to friction.

Potential energy is a scalar quantity.

Practical applications:

- bow and arrow

Quantitative requirements relating to potential energy of position will be limited to position of an object in a gravitational field and for a spring.

Compare the potential energy of a book raised to the ceiling with its potential energy resting on the edge of a desk.

The field concept may be introduced by diagraming or modeling gravitational fields. A gravitational field is the space where a gravitational force is exerted on a mass. The gravitational field lines of the Earth are directed radially inward towards its center, the direction in which a test mass would travel if released.

*a. Gravitational potential energy

If work is done on an object against the gravitational force, there is an increase in the gravitational potential energy of the system.

If work is done by the gravitational force on an object, there is a decrease in the gravitational potential energy of the system.

For displacements that are small compared with the radius of the Earth, the change in gravitational potential energy of an object is equal to the product of its weight and the vertical change in height.

$$\Delta PE = mg\Delta h$$

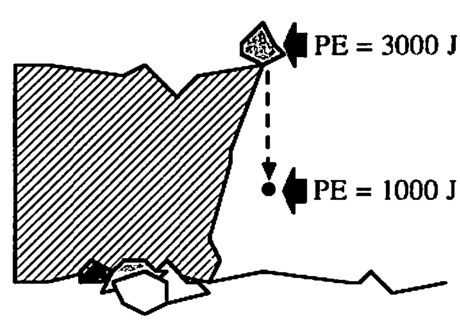
Since $w = mg$, $\Delta PE = w\Delta h$.

Practical applications:

- throwing a ball upwards
- hydroelectric plant
- piledriver

The expression "gravitational potential energy" refers to the gravitational potential energy of the mass – Earth system, not the gravitational potential energy of the mass alone. Energy is stored in the system, not the mass.

For short distances above the surface of the Earth (up to an altitude of about 16 km), g is considered to be a constant.



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*b. Elastic potential energy

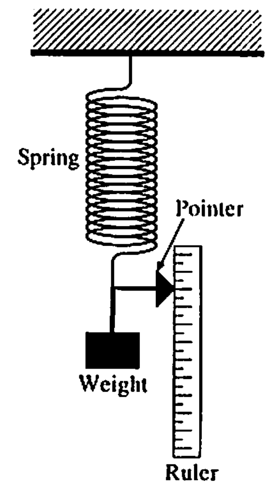
When work is done on a spring in compressing or stretching it, potential energy is stored in the spring.

The slope of a force-displacement graph is the spring constant, k.

Practical applications:

- toys
- spring scale
- mattress spring
- dart pistol gun

Students are required to determine the relationship between the force applied to a spring and the elongation of the spring and graph the results.



$$F = kx$$

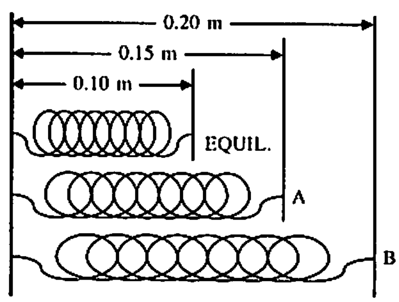
The newton/meter, N/m, is the SI unit for the spring constant.

In the equation, $F = kx$, F is the force exerted on the spring.

Try Hooke's Law experiments with rubber bands and plastic garbage bags.

The potential energy stored in the spring is equal to one-half the product of the spring constant and the magnitude of the square of the distance by which the spring has been compressed or stretched from its original length.

$$PE_s = \tfrac{1}{2} kx^2$$



at EQUIL., $PE_s = 0$
at A, $PE_s = .2J$
at B, $PE_s = .8J$

It is highly recommended that the expression for spring potential energy be derived empirically by performing a Hooke's Law demonstration. Plot a force-displacement graph and determine the spring constant by taking the slope of the graph. The potential energy stored in the spring can be determined by finding the area under the curve.

As a spring is compressed, the force increases. The equation for potential energy is based on the average force. Since $F = \tfrac{1}{2}kx$ and $W = Fx$, $W = PE = \tfrac{1}{2}kx^2$

*2. Kinetic energy

Kinetic energy is the energy an object has because of its motion.

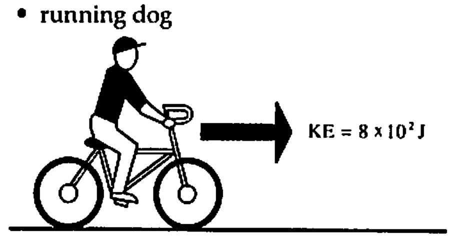
The kinetic energy of an object is equal to one-half the product of its mass and the square of its velocity.

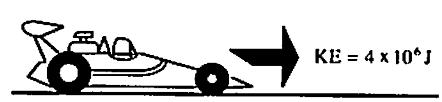
$$KE = \tfrac{1}{2} mv^2$$

Kinetic energy is a scalar quantity.

Practical applications:

- moving train
- soaring bird
- running dog





The square of a vector quantity, in this case velocity, results in a scalar quantity, because a vector dot product is involved:

$v \cdot v = vv \cos\theta$; when $\theta = 0°$, $v \cdot v = v^2$

The scalar product of two vectors is the product of the magnitude of one vector and the component of the other vector in the direction of the first.

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***D. Work-energy relationship**

The work done by a force in moving an object is equal to the sum of the change in potential energy, the change in kinetic energy, and the work done against friction.

1. Conservative force
   A conservative force is one for which the work done on an object is independent of the path taken. Potential energy can be defined only for a conservative force.
2. Non-conservative force
   A non-conservative force is one for which the work done on an object depends upon the path taken. Friction is a non-conservative force.

Practical applications:

- roller coaster
- "Hot Wheels" car
- toys
- ski jump

Quantitative requirements are limited to problems in which the work done is equal to the sum of the change in potential energy, the change in kinetic energy, and the work done against friction.

Review the force of friction with demonstrations and/or laboratory exercises.

***E. Conservation of energy**

In any transfer of energy among objects in a closed system, the total energy of the system remains constant.

A closed system is one where no external forces act and no external work can be done on or by the system.

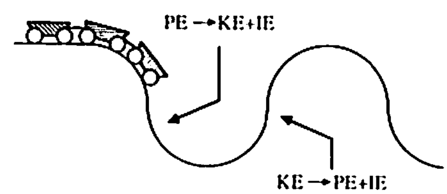
The change in energy of a system is equal to the change in kinetic energy plus the change in potential energy plus the change in internal energy.

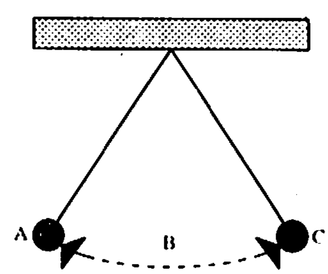
If no nonconservative forces are present in a system, the sum of the changes in potential energy and kinetic energy is equal to zero.

Unifying theme: Conservation of energy

Practical applications:

- pendulum clock
- bouncing ball





In the absence of friction:
at A, PE = 10 J, KE = 0
at B, PE = 0, KE = 10 J
at C, PE = 10 J, KE = 0

For mechanical systems, the sum of the kinetic and potential energies is called the total mechanical energy.

Work done against friction in a mechanical system is converted to heat or internal energy.

Practical applications:

- meteor
- re-entering space vehicle

Friction always does negative work because it removes mechanical energy from the system.

Discuss the impossibility of a perpetual motion machine.

If the optional unit "Internal Energy" is to be discussed, this would be an appropriate introduction to it.

Unit Three

ELECTRICITY AND MAGNETISM

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I. STATIC ELECTRICITY		
Static electricity deals with electrical charges at rest.	*Dancing on a nylon carpet can cause sparks to fly.* Unifying Theme: Conservation of charge	The term 'at rest' indicates that the net flow of charge in any given direction is zero. It should not be implied that the charges themselves are not in motion. Since this material is usually covered in science 7-8-9 and in chemistry, only a brief review of atomic structure should be necessary at this point.
A. Micro structure of matter The basic unit of molecular structure is the atom. Three of the units of which atoms are composed are electrons, protons, and neutrons. Electrons are negatively charged, protons are positively charged, and neutrons are neutral. The protons and neutrons are found in the nucleus of the atom. The electrons are found outside the nucleus. Neutral atoms have equal numbers of electrons and protons. Protons are not readily removed from the nuclei of atoms.	Practical applications: • the atom	Protons and neutrons in the nucleus are held tightly together by nuclear forces. Protons and neutrons are relatively massive compared to electrons. The electrons are more loosely bound by electrical forces outside the nucleus, and, as a result, electrons rather than protons are transferred in a charging process. The electron and the proton have charges which are equal in magnitude and opposite in sign. The magnitude of the charge on an object occurs in multiples of e, the elementary charge unit. Protons, neutrons, and mesons are composed of groups of quarks, which have charges of $\pm$ e/3 and $\pm$ 2e/3. However, these quarks cannot be isolated.
B. Charged objects An object which has a deficiency of electrons is charged positively; one which has an excess of electrons is charged negatively; and one with an equal number of electrons and protons is neutral.	*The copy machine in the office and lightning have a great deal in common.* Unifying themes: Conservation of charge Use electroscopes in laboratory exercises to determine the sign of a charge. Describe the behavior of a charged electroscope when objects with the same and opposite charge as the electroscope are brought near it.	
	During the summer months, static cling in clothes is generally not a problem.	In damp weather, a blow dryer may be used to improve the results of experiments in static electricity.

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Unlike charges attract and like charges repel. The charging process occurs by an exchange of electrons.	Practical applications: • photocopy machine • lightning • electrostatic precipitators	
Grounding either removes or adds electrons to the object to neutralize the charge.	Practical applications: • lightning rods • ground wire in an electrical apparatus	
C. Conservation of charge		
The net charge in a closed system is constant. Charges may be transferred from one object to another.	Use conservation of charge and symmetry to predict the results when identical charged conducting objects are placed in contact.	Conservation of charge is a universal law. Pair production is an example of conservation of charge. If a neutral hard-rubber rod is rubbed with neutral, clean plastic wrap, it can be shown with an electroscope that both are charged, one positive and the other negative.
D. Elementary charges		
Any charge is made up of integral multiples of a minimum charge called the elementary charge. The charge of the electron is one negative elementary charge. The charge of a proton is one positive elementary charge.	Practical applications: • proton • electron	
***E. Quantity of charge**		
The quantity of charge a body possesses depends on its excess or deficiency of electrons. The coulomb, C, is the SI unit of charge. It is a derived unit. 1 coulomb = 6.25×10^{18} elementary charges	Quantitative requirements are limited to conversions between elementary charges and coulombs.	The coulomb is defined in terms of the ampere which will be considered in a later section. The elementary charge, e, has a magnitude of 1.60×10^{-19} coulomb. Therefore, a coulomb of charge represents an excess or deficiency of $\dfrac{1.00\text{ coulomb}}{1.60 \times 10^{-19}\,\dfrac{\text{coulomb}}{\text{electron}}}$ or 6.25×10^{18} electrons.
***F. Coulomb's law**		
The electrical force between two point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them. $F = \dfrac{kq_1q_2}{r^2}$ The value for the electrostatic constant, k, (in a vacuum or air) is $9.00 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$.	Practical applications: • the atom	Charged objects may be considered to be point charges when they are small compared to the distance between them. Substitution of sample values gives large forces for coulomb-sized charges and lab-sized forces for charges in the microcoulomb range. The Coulomb force that exists between two point charges is an example of Newton's Third Law. Stress that the force is applied to each object.

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The Coulomb force is equal in magnitude and opposite in direction for each object, directed along the line joining the charges.

***G. Electric fields**

An electric field is said to exist in any region of space in which an electric force acts on a charge.

An electric field exists around every charged object. The electric field intensity is a vector quantity.

The magnitude of the strength of an electric field at any point is the force per unit charge at that point in the electric field. The direction of the field is the direction of the force on a positive charge.

$$E = \frac{F}{q}$$

The newton/coulomb, N/C, is the SI unit for electric field strength.

1. Electric field around a point charge

The field around a point charge is radial.

The electric field around a charged conducting sphere acts as though all the charge were concentrated at the center. The field within a charged conducting sphere is zero.

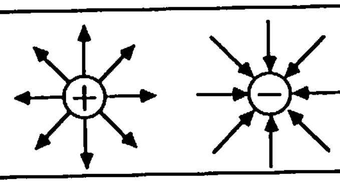
The intensity of the electric field varies inversely with the square of the distance from the point charge.

Unifying themes: Fields, Vectors, Conservation of energy.

Practical applications:

- coaxial cable (electric shielding)

Students should be able to draw electric field diagrams for point charges and parallel plates and to determine the direction of the net force on a point charge placed in the field.



Arrows show the direction of the electric field.

Draw diagrams showing the electric field for like charges and unlike charges near each other.

Electric field strength is the force per unit charge, while gravitational field strength is the force per unit mass.

The electric field may be detected by the introduction of a test charge into the field.

In the equation, $E = F/q$, q is *not* the original charge creating the field; q is a charge brought into the field.

The similarity between the electric field around a point charge or a uniformly charged spherical body and the gravitational field around a sphere should be emphasized.

From the relation $E = F/q$, it follows that the force exerted on a charge in an electric field is the product of the charge and the field intensity. In the SI system, the unit for E is the newton/coulomb. In comparison, the gravitational field strength ($g = F/m$) can be expressed in newtons/ kilogram.

The field around a uniformly charged sphere is similar to that of a point charge. For any charged conductor whose charges are at rest, the field lines are normal to its surface.

The inverse square law for the electric force between two point charges has been verified experimentally to a high degree of accuracy.

For the field of a point charge being measured with a point test charge, q_2:

$$E = \frac{F}{q} = \frac{kq_1q_2/r^2}{q_2} = \frac{kq}{r^2}$$

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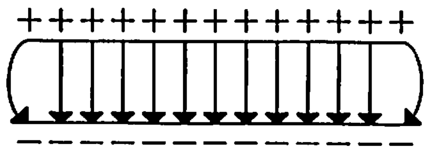
2. Electric field between two parallel plates The electric field between two parallel charged plates is essentially uniform if the distance between the plates is small compared to the dimensions of the plates.		The essentially uniform nature of the field between parallel plates produces a very nearly constant force on a given charge placed anywhere in the field except near the edges of the plates.
3. Electric potential The electric potential at any point in an electric field is the work per unit charge required to bring one coulomb of positive charge from infinity to that point. Electric potential is a scalar quantity.		When a charge is moved against the force of an electric field, work is done on the charge, and its electric potential energy is increased. When the charge moves in response to the field, work is done by the field and its potential energy is decreased. In both cases energy is conserved.
***H. Potential difference** The potential difference between two points in an electric field is the change in potential energy per unit charge as a charge is moved from one point to the other. $V = \frac{W}{q}$	Practical applications: • batteries • household electricity • power transmission lines • Van de Graaff generators	The similarity between electric and gravitational potential energy should be noted. Distinguish between electric potential and potential energy.
1. The volt The volt, V, is the SI unit of electric potential and potential difference. The volt is the potential difference that exists between two points if one joule of work is required to transfer one coulomb of charge between these two points against the electric field. 1 volt = 1 joule/coulomb		The students should become familiar with voltage magnitudes of common devices. Most electric cells yield 1 to 2 volts.
*2. The electronvolt An electronvolt, eV, is the energy required to move one elementary charge through a potential difference of one volt. 1 electronvolt = 1.60×10^{-19} joule	Practical applications: • energy of photons • measuring bandgaps in semiconductors • energy levels in atoms Quantitative requirements include conversions between electronvolts and joules.	The student should become familiar with examples of energy exchanges in terms of eV. For example, chemical bonding involves 1 to 2 eV and visible light photons carry about 1 to 2 eV (and thus cause chemical changes). Energies of particles used in nuclear research are measured in MeV, GeV (BeV), and TeV.
*3. Electric field in terms of electric potential The intensity of a uniform electric field is the rate at which electric potential changes with position.	Practical applications: • charged parallel plates	The formula E = V/d is valid only for a uniform electric field. The equivalence of volt/meter and

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$$E = \frac{V}{d}$$

The volt/meter, V/m, is a unit for electric field intensity.

newton/ coulomb may be shown as follows:

$$1 \text{ volt} = \frac{1 \text{ joule}}{\text{coulomb}}$$

$$1 \text{ volt} = \frac{1 \text{ newton}\cdot\text{meter}}{\text{coulomb}}$$

$$\frac{1 \text{ volt}}{\text{meter}} = \frac{1 \text{ newton}}{\text{coulomb}}$$

Students should become familiar with the magnitudes of electric fields, such as mV/m for radio reception.

II. ELECTRIC CURRENT

An electric current is a flow of electric charge.

It is measured by the rate at which electric charge flows past a given point.

Since the word "current" means a flow of charge, the use of such phrases as "current flow" is, strictly speaking, redundant. However, the use of terms which are in general use may clarify concepts.

A. Conductivity in solids

Solids vary in their ability to conduct an electric current.

The conductivity of solids depends on the number of free charges per unit volume and the mobility of the charges.

Conductors are substances in which there are many free electrons.

Insulators are substances in which there are few free electrons.

The outer electrons are not bound or are only loosely bound to particular atoms of a conducting material.

The outer electrons are tightly bound to the atoms of an insulating material.

Practical applications:

- copper
- aluminum
- electrical wire

In general, metals are good conductors of electricity and nonmetals are poor conductors.

It is left to the teacher to decide whether to use electron current (- to +) or conventional current (+ to -).

The resistivity of a material is a numerical indication of how well the material conducts electricity. The resistivity of copper is $1.7 \times 10^{-8}\ \Omega\cdot m$; the resistivity of aluminum is $2.8 \times 10^{-8}\ \Omega\cdot m$

No solid is a perfect insulator, but in some solids, such as glass and fused quartz, the conductivity is so low that, for practical purposes, they may be considered nonconductors.

B. Conditions necessary for an electric current

A potential difference is required to create a flow of charge between two points in a conductor. The conductor must form a complete circuit to maintain a flow of charge.

Symbols for:

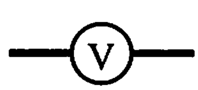
a cell

a battery

Some materials whose outer electrons are more tightly bound to their atoms than for conductors, but less tightly bound than for insulators, are called semiconductors. Their resistivities lie between conductors and insulators.

The potential difference in a circuit may be supplied by a battery.

A voltmeter is used to measure potential difference.



Symbol for a voltmeter

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***C. Unit of current**

A current of one ampere transfers charge at the rate of one coulomb per second.

$$I = \frac{\Delta q}{\Delta t}$$

The ampere, A, is the SI unit of electric current. It is a fundamental unit.

An ammeter is used to measure current.

Symbol for an ammeter:

The formal definition of the ampere will be introduced after the requisite concepts have been developed in the section on magnetism.

AC considerations are excluded.

D. Resistance of a conductor

1. Ohm's Law

At constant temperature, the current in a metallic conductor is directly proportional to the potential difference between its ends and inversely proportional to its resistance.

Ohm's Law is often expressed mathematically as $V = IR$. It should be stressed that Ohm's Law is specific for certain materials and not a general law of electricity. However, since this relationship holds for metallic conductors at constant temperature found in ordinary electric circuits, it is of great practical importance.

*2. Resistance

Resistance is the ratio between potential difference across and current in a conductor.

$$R = \frac{V}{I}$$

The ohm, Ω, is the SI unit of resistance. It is a derived unit.

Symbol for resistance:

The slope of a potential difference – current graph is resistance for a metallic conductor at constant temperature.

The resistance is the constant of proportionality in Ohm's Law.

In vacuum tubes, transistors, gas discharge tubes, and electrolytic cells, Ohm's Law does not apply, so that voltage versus current graphs are not linear.

Incandescent lightbulbs experience an increase in temperature as they are used, resulting in an increase in resistance.

3. Resistance in a conductor

The resistance of a conductor of uniform cross section and composition varies directly as its length and inversely as its cross-sectional area. In general, the resistance of metals increases with increasing temperature.

Short, fat, cold wires are better conductors than long, thin, hot wires.

Practical applications:

- superconductor
- transistor
- computer chip
- lightbulb
- electrical resistance thermometer

The resistance of nonmetals and solutions usually decreases with increasing temperature.

At relatively low temperatures some materials have zero resistance. This phenomenon is known as superconductivity. Research is currently taking place to increase the temperature at which superconductivity occurs.

In some materials, for example certain semiconductors, the relationship between temperature and resistance depends upon the temperature range.

E. Circuits

A circuit is a closed path in which a current can exist.

Circuit components may be connected in series or in parallel or in combinations of these.

A 30-watt lightbulb can be brighter than a 60-watt lightbulb.

Students are required to draw circuit diagrams.

Connect voltmeters and ammeters in circuits to measure potential difference and current.

Stress safety procedures when handling electrical apparatus.

Although series – parallel combination circuits are not required, they may be introduced.

Requirements are limited to series and parallel D C circuits.

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For any junction in a circuit the sum of the currents entering the point is equal to the sum of the currents leaving it.

Unifying theme: Conservation of charge

This is known as Kirchoff's first law.

For any simple circuit loop, the sum of the potential drops is equal to the source.

Unifying theme: Conservation of energy

This is known as Kirchoff's second law.

*1. Series Circuits

A series circuit is one in which there is only one current path.

The current is the same in all the components of a series circuit.

$I_t = I_1 = I_2 = I_3 = \ldots$

The sum of the potential drops in a series circuit is equal to the source.

$V_t = V_1 + V_2 + V_3 + \ldots$

The total resistance of a series circuit is equal to the sum of the resistances of its components.

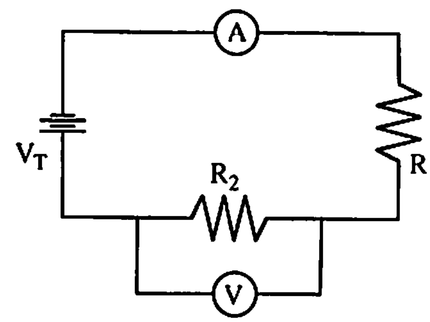
$R_t = R_1 + R_2 + R_3 + \ldots$

Ammeters are connected in series in a circuit.

Practical applications:

- holiday tree lights
- fuse
- circuit breaker
- thermal switch (bimetallic strip) in a hair dryer

Students are required to set up a series circuit consisting of a source of potential and two resistances. They must determine the potential difference across and the current through each resistance and the circuit as a whole.



The expression for the total resistance of a series circuit may be derived as follows:

$V_t = V_1 + V_2 + V_3 + \ldots$

Where $V = IR$

Thus, $I_t R_t = I_1 R_1 + I_2 R_2 + I_3 R_3 + \ldots$

But $I_t = I_1 = I_2 = I_3 = \ldots$

So $R_t = R_1 + R_2 + R_3 + \ldots$

*2. Parallel circuits

A parallel circuit is one in which there is more than one current path.

The potential drop is the same across each branch of a parallel circuit.

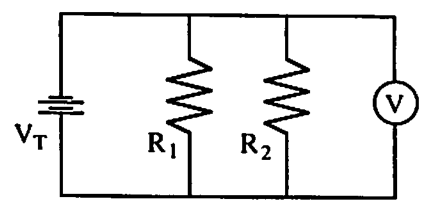
$V_t = V_1 = V_2 = V_3 = \ldots$

Practical applications:

- electrical devices plugged into outlets
- jump starting a car
- overloaded circuit

The devices in a car are usually connected in parallel across the battery.

The difference between parallel and series circuits can be observed by connecting three resistances in series and then in parallel. In each circuit determine the potential difference and current for each resistance and for the circuit as a whole.



The total current in a parallel circuit is the current supplied by the source and is equal to the sum of the branch currents.

$I_t = I_1 + I_2 + I_3 + \ldots$

The reciprocal of the equivalent or total resistance of a parallel circuit is equal to the sum of the reciprocals of the branch resistances.

Students are required to set up a parallel circuit consisting of a source of potential and two resistances. They must determine the potential difference across and the current through each resistance and the circuit as a whole.

The expression for the equivalent resistance of a parallel circuit may be derived as follows:

$I_t = I_1 + I_2 + I_3 + \ldots$

Where $I = V/R$

Thus, $\frac{V_t}{R_t} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \ldots$

But $V_t = V_1 = V_2 = V_3 = \ldots$

So $\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$

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$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

Voltmeters are connected in parallel in a circuit.

*3. Electric power

Electric power is the time rate at which electric energy is expended.

The watt, W, is the SI unit for electric power.

It is a derived unit.

Power is equal to the product of current and potential difference. For conductors which obey Ohm's Law, it can be applied to obtain expressions involving resistance.

$P = VI$ for any general device

$P = VI = I^2R = V^2/R$ for ohmic conductors

Electric power is a scalar quantity.

Practical applications:

- power rating on lightbulbs and appliances
- dimmer switch

Substituting units into the formula $P = VI$ yields:

$$P = \frac{\text{joule}}{\text{coulomb}} \cdot \frac{\text{coulomb}}{\text{second}}$$

$$P = \frac{\text{joule}}{\text{second}}$$

$P = \text{watt}$

Since the joule is a small unit of energy, commercial electrical energy is usually measured in kW•hr. One kW•hr = 3.6×10^6 J.

*4. Electric energy

The energy used in an electric circuit is the product of the power developed and the time during which the charges flow.

$W = Pt = VIt = I^2Rt$

The joule, J, is the SI unit for electric energy. It is a derived unit. Electric energy is a scalar quantity.

Practical applications:

- household electric bill
- household electric meter

Unifying theme: Conservation of energy

One reason for boosting the potential in power lines is to reduce the current and thus reduce the loss of energy.

Compare the efficiency of incandescent lights with fluorescent lights.

III. MAGNETISM

A. Magnetic force

Magnetic force is a force that exists between currents.

Iron fences become magnetized after standing in the same place for many years.

The general properties and uses of magnets and the compass should have been taught in previous courses. A review of these concepts may serve as an introduction to this section.

B. Magnetic field

Magnetic fields exist in the regions around electric currents.

1. Direction

The direction of a magnetic field is, by convention, the direction in which the N-pole of a compass would point in the field.

Practical applications:

- the Earth
- magnetic compass

Unifying theme: Fields

Paramagnetism is due to electron spin in the atoms of a material. Ferromagnetism is also due to electron spin, but a quantum effect is responsible for aligning the spins of many atoms. Diamagnetism is due to a displacement of electron orbital arrangements.

The north pole of the Earth's magnetic field is located near the South Pole of the Earth.

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2. Magnetic flux lines A magnetic field is mapped by imaginary magnetic lines of force called flux lines. The lines of force always form closed paths and never cross. The magnitude of the magnetic field is greatest where the lines of force are closest together. The direction of the magnetic field at any point is tangent to the field line at that point.	Students are required to map the magnetic field around a magnet. Practical applications: • bar magnet • Earth	Magnetic fields can be demonstrated b using iron filings near a magnet. Students should become familiar wit the magnitudes of several common mag netic fields. For example: research electromagnet 1-2 T Earth's surface 5×10^{-5} T (.5 gauss)
3. Flux density The magnetic flux density (magnetic field strength) at a point in a magnetic field is the flux per unit area taken perpendicular to the flux at that point. Flux density is a vector quantity. The tesla, T, is the SI unit of flux density.	Unifying theme: Vectors	Permeability is the property of a materi which permits the flux density to b greater than it would be in a vacuum. The permeability of air is nearly the sam as that of a vacuum which is one. The flux density between the poles magnets (such as surplus magnetrons) often given in gauss. 1.0 tesla = 1.0 weber/meter^2 1.0 tesla = 1.0×10^4 gauss
4. Magnetic field around a straight conductor. An electric current in a straight conductor creates a magnetic field that may be represented by magnetic lines of force that are concentric circles, having the wire as a common center, and in a plane perpendicular to the conductor.	Determine the direction of a field around a conductor by using an appropriate hand rule.	It is left to the teacher to decide wheth to use left-hand rules or right-han rules.
5. Magnetic field around a coil of wire (solenoid). An electromagnet is a coil of wire with a ferromagnetic core.	*A piece of iron can turn a weak solenoid into a strong electromagnet.* Practical applications: • loud speaker • electromagnet • electric motor • circuit breaker • galvanometer Determine the direction of a field around a coil using an appropriate hand rule.	
C. Force on a moving charge carrier in a magnetic field The force on a moving charge carrier in a magnetic field is perpendicular to the direction in which the charge carrier is moving and to the magnetic field vector at that point.	Practical applications: • cathode ray tube • mass spectrometer	The direction of the force may be det mined by considering the increase of fl density on one side of the charge carr (additive fields) and the decrease on t other side of the charge carrier (subtr.

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The force is a maximum when the angle between the field and the direction of motion of the charge carrier is 90°. There is no force when the angle between the field and the direction of motion of the charge carrier is 0°.	Determine the direction of the force on a moving charge carrier by using an appropriate hand rule.	tive fields). The charge carrier moves toward the weaker field. If the optional unit "Electromagnetic Applications" is to be discussed, the sections on meters and motors may be introduced here. The force between parallel conductors is used to define the ampere. A current of one ampere is that current which, when flowing in each of two parallel wires one meter apart, causes the wires to exert a force on each other of 2×10^{-7} newton for each meter of their length.
IV. ELECTROMAGNETIC INDUCTION A potential difference may be induced in a conductor. The magnitude of the induced potential difference is proportional to the rate at which the flux linked by the conductor changes.	Unifying Theme: Conservation of energy Practical applications: • generator • transformer	The induced potential difference depends on the rate at which the flux is changing, whether that change is because the flux is changing in magnitude or direction, or because of any motion of the conductor that causes a change in flux.
A. Electromagnetic radiation Electromagnetic waves are generated by accelerating electric charges.	Unifying themes: Fields Practical applications: • electromagnetic spectrum • antenna	Accelerating charges produce oscillating electric and magnetic fields which are perpendicular to each other.

No Sound WAVES
Can use for demo's
but not Required

Unit Four
WAVE PHENOMENA

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I. INTRODUCTION TO WAVES

A wave is a vibratory disturbance that propagates through a material or space.

Unifying theme: Conservation of energy

A medium is the material through which a wave passes and is required for the transfer of mechanical waves, e.g. water waves, sound waves, rope waves and spring waves.

A. Transfer of energy

Wave motion transfers energy from one point to another with no transfer of mass between the points.

Sound from a rifle firing could trigger an avalanche.

Practical applications:

- sound
- water
- light

Particles of the medium vibrate around rest (equilibrium) positions, but do not move along the wave as the energy does.

In the case of electromagnetic waves, where the waves are periodic disturbances of electromagnetic fields and no medium is necessary, the term "space" or "vacuum" will be used.

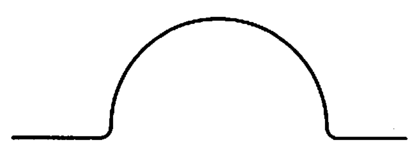
Wave behavior in a medium is more easily studied and is therefore used here to establish typical patterns as exhibited by all waves.

B. Pulses and periodic waves

A wave may be classified as a pulse or a periodic wave.

1. Pulses in a medium

A pulse is a single vibratory disturbance that moves from point to point.



A ripple tank may be used to demonstrate both pulses and periodic waves.

Suspend a long coiled spring from the ceiling to demonstrate wave phenomena.

Use ripple tanks to demonstrate wave phenomena.

a. Speed of a pulse

In a uniform medium, a pulse has a constant speed.

The speed of a pulse is dependent on the type and properties of the medium.

b. Reflection and refraction

When a pulse reaches a boundary with a different medium, part of the pulse is reflected, part will be transmitted through the second medium, and part will be absorbed.

Practical applications:

- one-way mirror
- sound-proofing
- concert hall design

Discuss design features used in active and passive solar energy systems, such as painting the back surface of a solar collector black and placing windows on the south side of a house.

2. Periodic waves

A periodic wave is a series of regular (evenly timed) disturbances in a medium.

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C. **Types of wave motion**

Two simple types of wave motion are longitudinal and transverse.

The longitudinal and transverse nature of earthquake waves provide evidence for the structure of the Earth's interior.

1. Longitudinal waves

The vibratory disturbance in longitudinal waves is parallel to the direction of travel of the wave.

Practical applications:
- sound
- seismic waves (P-waves)

2. Transverse waves

The vibratory disturbance in transverse waves is at right angles to the direction of travel of the wave.

Practical applications:
- electromagnetic waves
- seismic waves (S-waves)

Water ripples are approximately transverse. Waves in a cord are transverse.

II. CHARACTERISTICS OF PERIODIC WAVES

A. **Frequency**

Frequency is the number of vibrations occurring per unit time.

The hertz, Hz, is the SI unit of frequency. It is a derived unit.

1 hertz = 1 cycle/second

Practical applications:
- radio frequencies
- tuning fork
- sonar
- dog whistle

The human ear can detect sound frequencies in the range of 20 Hz to 20,000 Hz.

A frequency of one hertz is equal to one vibration per second. This definition is now standard and should be stressed.

Ultrasonic sound is used to study body organs, map the ocean floor, locate mineral deposits, and clean equipment and eyeglasses.

*B. **Period**

The period is the time required for completion of a single vibration.

The second, s, is the SI unit for period.

The period is the reciprocal of the frequency.

$$T = \frac{1}{f}$$

Practical applications:
- period of a pendulum

C. **Amplitude**

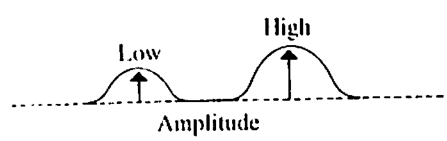
The amplitude of a wave is the maximum displacement of a particle of the medium from the rest position.

As the amplitude of a light wave increases, the brightness of the light increases.

As the amplitude of a sound wave increases, the loudness of the sound increases.

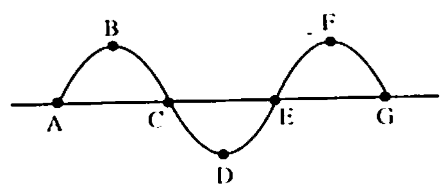
Compare the relative amplitudes of waves from diagrams.

Practical applications:
- boom box
- rock concert
- threshold of pain
- dimmer switch on a light switch



D. **Phase**

Points on a single periodic wave having the same displacement from their equilibrium position and moving in the same direction are said to be in phase.



Points in phase: A+E
B+F
C+G

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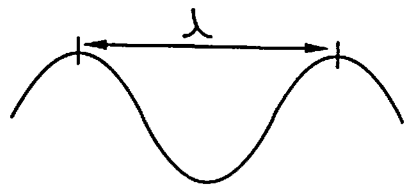
E. Wavelength

The wavelength of a periodic wave is the distance between two consecutive points in phase.

The wavelength can be measured from one point on a wave to an identical point on the same wave.



***F. Speed**

The speed of a wave is equal to the product of the frequency and the wavelength.

$$v = f\lambda$$

To begin the race, you look for the flash of the starting pistol instead of listening for the sound.

The bat is seen hitting the ball before the crack is heard.

The relationship $v = f\lambda$ may be considered an application of $s = vt$. The distance λ is covered by the wave of velocity v in one period:

$\lambda = vT = v/f$ or $v = f\lambda$.

G. Doppler effect

The Doppler effect is the variation in observed frequency when there is relative motion between a source and a receiver.

There is an increase in observed frequency when the distance between a source and a receiver is decreasing.

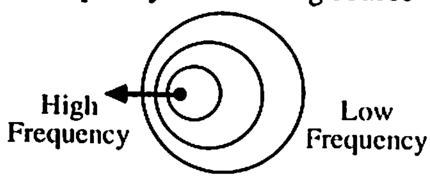
There is a decrease in observed frequency when the distance between a source and a receiver is increasing.

Changes in sound frequency are observed as changes in pitch. Changes in light frequency are observed as changes in color.

Practical applications:

- train whistle
- passing car's horn
- radar
- red shift of starlight
- measuring the speed of a baseball

Frequency & a moving source



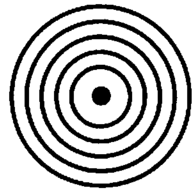
- A ripple tank demonstration may be used to illustrate the Doppler effect and the compression of waves. A "water boom" can be created which is analogous to a sonic boom.

Observations of the red shift of light from distant galaxies support the Big Bang theory of the formation of the universe.

Tuning forks or a signal generator and an oscilloscope may be used to demonstrate pitch.

H. Wave fronts

A wave front is the locus of adjacent points of the wave which are in phase.



A ripple tank may be used to demonstrate wave fronts.

III. PERIODIC WAVE PHENOMENA

Periodic waves respond to different conditions in predictable ways.

A. Interference

Interference is the effect produced by two or more waves which are passing simultaneously through a region.

1. Superposition

The resultant displacement at any point is the algebraic sum of displacements due to individual waves.

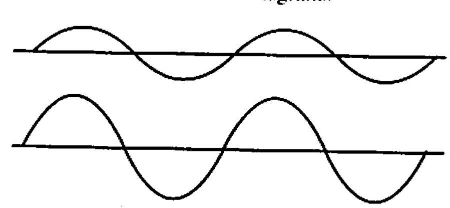
Two waves can be less disturbing than one.

Practical applications:

- beats
- concert seating

Interference may be demonstrated using a ripple tank.

Paired Wave Diagrams



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a. Constructive interference

Maximum constructive interference occurs at points where the phase difference is 0°.

Constructive

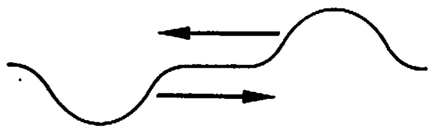
To illustrate constructive and destructive interference, two transparencies depicting identical waves in different colors may be used. A third blank transparency can be placed on top and the resultant sketched for various phase relationships.

b. Destructive interference

Maximum destructive interference occurs at points where the phase difference is 180°.

Maximum destructive interference results in the formation of nodal points and nodal lines.

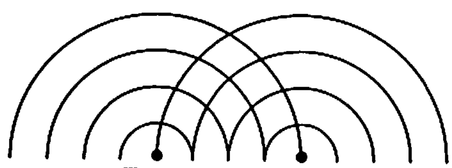
The total destruction of two coincident periodic waves results if they have equal amplitudes and frequencies and a phase difference of 180°.



Destructive

2. Two sources in phase in the same medium

Two wave sources operating in phase in the same medium produce wave trains forming symmetrical interference patterns where the waves meet.



Two sources in phase

Constructive interference occurs at points where path distances to the two sources differ by an even number of half-wavelengths, resulting in a phase difference of 0° or 360°.

Identify constructive interference at specific points on a diagram of two sources in phase.

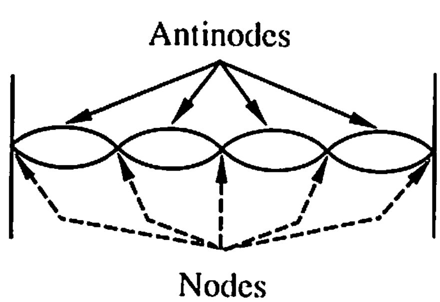
Destructive interference occurs at points where path distances to the two sources differ by an odd number of half-wavelengths, resulting in a phase difference of 180°.

Identify destructive interference at specific points on a diagram of two sources in phase.

3. Standing waves

Standing waves are produced when two waves of the same frequency and amplitude travel in opposite directions in the same medium.

Identify nodes and antinodes from standing wave diagrams.

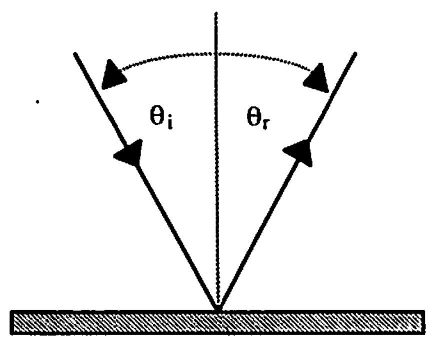


Standing waves in a stretched string may be demonstrated using a sonometer. Paper riders will show locations of nodes and antinodes. It should be noted that the string must contain an integral number of half-wavelengths.

Standing waves have important implications for atomic and nuclear physics which should be discussed at the appropriate time in that optional area.

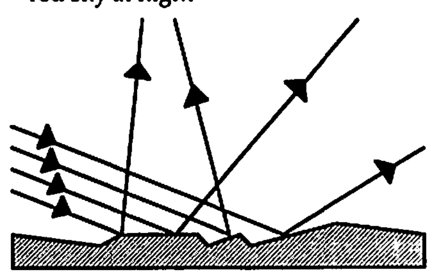
Content Outline/ Understandings/ Concepts	Discrepancies/ Practical Applications/ Activities	Supplementary Information
a. Reflection Standing waves are most often produced by reflection of a wave train at a fixed boundary of the medium.		
b. Resonance causes vibrations in an object at the object's natural vibration frequency by a wave with the same frequency. Most vibrating systems will vibrate at a particular frequency if disturbed. If they are excited at the resonant frequency, the amplitude will increase.	*Ben Franklin made a musical instrument with glasses partially filled with water.* Practical applications: • structural design (Tacoma Narrows Bridge collapse) • behavior of atoms • music and acoustics • opera singer shattering a glass • marching band breaking step when crossing a bridge	Resonance may be demonstrated using a matched pair of tuning forks. Emphasize the importance of standing waves in producing resonance.
IV. LIGHT Light is an electromagnetic disturbance that can produce the sensation of sight.	*You can see the flash of lightning before you hear the clap of thunder.*	No medium is necessary for the transmission of electromagnetic waves.
***A. Speed** The speed of light is equal to the product of frequency and wavelength. 1. In space The speed of light in space is an important physical constant, 3×10^8 m/s. $c = f\lambda$		To distinguish the speed of light from other wave speeds, the symbol "c" is to be used for the speed of light in a vacuum. Various methods for measuring the speed of light should be discussed. Measurements of the speed of light refuted the belief that the space between the Earth and sun was filled with "ether." The speed of light in space is the same in all reference frames and is the limit value for increases in speed.
2. In a medium The speed of light in a medium is dependent on the frequency of the light and on the nature of the medium.		The speed of light in a medium is always less than the speed of light in a vacuum. However, the speed of light in air is the same as that in a vacuum within three significant figures. Of all the possible paths between two points, a light ray will take the path which requires the least time. This is known as Fermat's principle and may be used to explain reflection.
B. Reflection 1. Law of reflection The incident ray, the reflected ray, and the normal to the surface at	Illustrate the law of reflection by ray diagrams.	Reflection results when waves strike a boundary of different impedence.

Content Outline/ Understandings/ Concepts	Discrepancies/ Practical Applications/ Activities	Supplementary Information
the point of incidence are in the same plane. The angle of reflection is equal to the angle of incidence. $\theta_i = \theta_r$	Construct plane mirror images using light ray diagrams and apply the law of reflection. Measure the angle of incidence and the angle of reflection.	Two students, a large mirror and string may be used to illustrate the law of reflection. One student observes the image of the second. The string is used to line up the image with the first student, is then fastened to the mirror, and is then run back to the second student. Angles can then be measured. Flat paint is used to paint the interiors of homes to minimize regular reflection which produces "hot spots."



Mirror

2. Regular reflection Regular reflection is reflection produced by polished surfaces, usually producing an image of the source.	Practical applications: • mirror • pool of water • looking out a window at night	
3. Diffuse reflection Diffuse reflection is the scattering of light caused by reflection from irregular surfaces.	Practical applications: • this paper • blue sky • red sky at night	The law of reflection holds for each light ray, but since the surface is irregular, the normals to the surface are not parallel and the reflected light is scattered.



Rough Surface

C. Refraction Refraction is the change in direction of a wave that occurs when the wave passes obliquely through a boundary and across which there is a change in speed.	*You can see the sun when it is below the horizon.*	An analogy such as a line of soldiers marching from smooth pavement into mud or the two right tires of a car going off the road into the mud may help explain the change in direction of a wave undergoing refraction.
1. Effect of the medium The speed of light waves depends on the properties of the medium.	Students are required to determine the path of a light ray passing from air	

Content Outline/ Understandings/ Concepts

2. Speed and refraction

When a wave enters a new medium obliquely, and there is a decrease in speed, the wave bends towards the normal (forms a smaller angle).

When a wave enters a new medium obliquely and there is an increase in speed, the wave bends away from the normal (forms a larger angle).

***D. Absolute Index of refraction**

The absolute index of refraction of a medium is the ratio of the speed of light in a vacuum to the speed of light in the medium.

$$n = \frac{c}{v}$$

*1. Snell's Law

The ratio of the absolute indices of refraction is inversely proportional to the ratio of the sine of the incident angle to the sine of the refractive angle.

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

and

$$n_1 v_1 = n_2 v_2$$

Discrepancies/ Practical Applications/ Activities

through another medium and back into air using a transparent object (rectangular block, semicircular container) and to draw the ray diagram.

Practical applications:

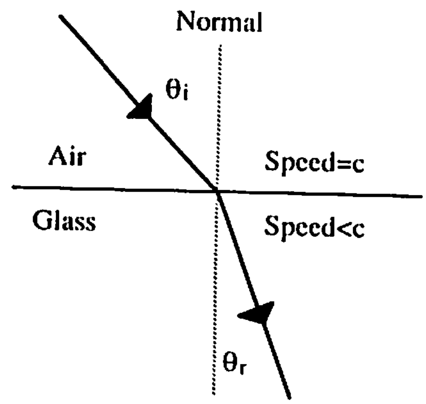
- twinkling star
- "water" on road on a summer's day

A straw appears to bend when placed in a glass of water.

Practical applications:

- a straight rod appearing bent in water
- distortion when looking into a fish tank
- one-way mirror

Supplementary Information



Immersion oil and glass have nearly the same indices of refraction, making the glass rod "disappear" when it is in the oil.

Relative index of refraction is represented by:

$$n_2/n_1 = n_{1,2}$$

It should be stressed that a subscript of "1" refers to the incident medium, and "2" to the refractive medium.

Given Snell's Law:

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{n_2}{n_1}$$

Where $n_1 = \frac{c}{v_1}$ and $n_2 = \frac{c}{v_2}$

It follows that

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{c/v_2}{c/v_1} = \frac{v_1}{v_2}$$

Since the frequency of the light does not change as the light travels into another medium

$$f_1 = f_2 = f$$

and

$v_1 = f\lambda_1$ and $v_2 = f\lambda_2$

Therefore,

$$\frac{v_1}{v_2} = \frac{f\lambda_1}{f\lambda_2} = \frac{\lambda_1}{\lambda_2}$$

Consequently,

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{n_2}{n_1} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$

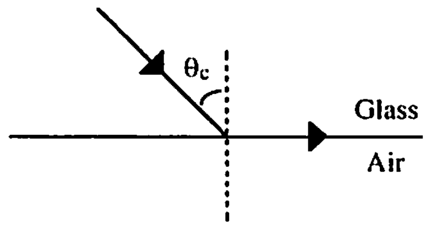
Content Outline/ Understandings/ Concepts	Discrepancies/ Practical Applications/ Activities	Supplementary Information

*2. Critical angle

The critical angle is the angle of incidence for which the angle of refraction is 90°.

$$\sin \theta_c = \frac{1}{n}$$

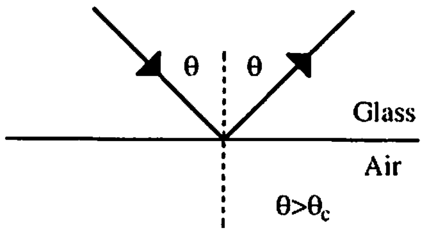
from one medium (n) into air or a vacuum (n = 1)



Snell's Law for the critical angle, $\sin \theta_c = n_2/n_1$, reduces to $\sin \theta_c = 1/n$ when the refractive medium is a vacuum or air.

3. Total internal reflection

Total internal reflection occurs when the angle of incidence is greater than the critical angle.



Telephone communications can be carried by laser beams through glass fibers.

Practical applications:

- fiber optics
- diamond
- rainbow

Total internal reflection occurs when light passes from one medium into another having a smaller absolute index of refraction with the incident angle greater than the critical angle.

4. Dispersion

Dispersion is the separation of polychromatic light into its component wavelengths as the light enters a dispersive medium obliquely.

Polychromatic light contains waves of different frequencies. Polychromatic light may be dispersed because each frequency of light has a different absolute index of refraction.

a. Dispersive medium

A dispersive medium is a substance in which the speed of a wave depends on its frequency. Glass is a dispersive medium for light.

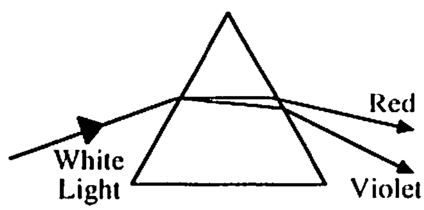
b. Non-dispersive medium

A non-dispersive medium is one in which the speed of the wave does not depend on the frequency. A vacuum is non-dispersive for light.

Red, blue, and green light make white.

Practical applications:

- diamond
- rainbow
- chandelier
- prism



Current use of ROY G BIV excludes indigo; i.e., ROY G BV.

Indices of refraction for glass:

violet light	1.53
yellow light	1.52
red light	1.51

Under everyday classroom conditions, air is a non-dispersive medium for light. The dispersive effect of air on light can be observed in the Michelson interferometer and, rarely, as a green flash as the sun sets.

Air is a non-dispersive medium for sound.

If the optional unit "Geometric Optics" is to be discussed, this is an appropriate introduction to it.

Content Outline/ Understandings/ Concepts	Discrepancies/ Practical Applications/ Activities	Supplementary Information

E. Wave nature of light

Much of the behavior of light can be interpreted in terms of wave phenomena.

1. Interference of light

Interference phenomena can be produced by light.

Interference can be explained by the wave model of light.

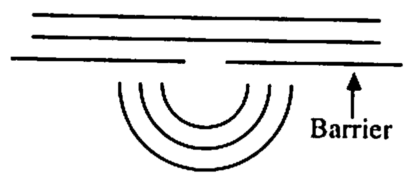
Practical applications:

- soap bubble
- oil slick on roadway

Commercial slits are available and can be used to demonstrate diffraction using a He/Ne laser.

a. Diffraction

Diffraction is the spreading of a wave into the region behind an obstacle.



Students can observe diffraction by looking at a light source through their fingers squeezed together.

According to Huygen's Principle, every point on a wave front may be considered a source of wavelets with the same speed.

Huygen's Principle provides a geometric method for predicting, from a known wave front shape, the shape of the wave front at a later time.

b. Coherent light sources

Sources producing waves with a constant phase relationship are said to be coherent.

Lasers produce nearly coherent light.

Conventional light is emitted in "packets" that are random in time and direction. Lasers produce light that is more coherent with groups of "packets" that are vibrating in phase in time and traveling in the same direction.

A laser produces a beam of light with a very narrow band of frequencies in which all the waves remain in phase for longer times than with ordinary sources.

*c. Double Slit

Light from two coherent point sources produces an interference pattern.

$$\frac{\lambda}{d} = \frac{x}{L}$$

Students can make their own double slits with two razor blades held tightly together being used to scratch lines on a blackened microscope slide.

The geometry of the double slit experiment and wave interference may be used to derive

$$\frac{\lambda}{d} = \frac{x}{L}$$

* NO SINGLE SLIT

Content Outline/ Understandings/ Concepts	Discrepancies/ Practical Applications/ Activities	Supplementary Information
2. Polarization Polarization is the separation of a beam of light so that the vibrations are in the same plane. Transverse waves can be polarized; longitudinal waves cannot be polarized.	Practical applications: • polarized sunglasses • 3-D movie • stress analysis	Polarization occurs because of the vibrations of the electric field in one plane. Observe the effect on light when two polarized film sheets are viewed at phase angles of 0° and 90°. Applications of various waves in the electromagnetic spectrum should be discussed. Discuss the greenhouse effect.
F. Electromagnetic spectrum The electromagnetic spectrum contains radio waves, infrared waves, visible light waves, ultraviolet waves, x-ray waves and gamma ray waves. The different effects of electromagnetic waves on receivers is due to differences in their frequency. Visible light is a small portion of the electromagnetic spectrum.	*You can get a sunburn on a cloudy day.* Unifying theme: Fields *Accelerating charges emit electromagnetic radiation.* Practical applications: • radio and television transmission • sunlight • sunburn • medical diagnosis • cancer treatment • sterilizing food • greenhouse • microwave oven	

Unit Five

MODERN PHYSICS

Content Outline/ Understandings/ Concepts	Discrepancies/ Practical Applications/ Activities	Supplementary Information

I. DUAL NATURE OF LIGHT

Light appears to exhibit the characteristics of either waves or particles in different experiments.

Unifying theme: Conservation of energy

Discuss the dual nature of electromagnetic radiation, including light. This dual nature illustrates that in order to conceptualize the behavior of light models must be used. When light waves are interact ing with each other, as in interference ef fects, a wave model is most effective Generally, however, when light interact with matter, a particle model is better. I the microscopic world, matter also re quires dual models for complete descrip tion.

A. Wave phenomena

Interference, polarization, and diffraction of light can be most easily explained on the basis of a wave theory.

Light can move objects.

B. Particle phenomena

The photoelectric effect can be explained most easily on the basis of a particle theory.

*1. Photoelectric effect

The photoelectric effect is the emission of electrons from a substance when illuminated by certain electromagnetic radiation.

Practical applications:

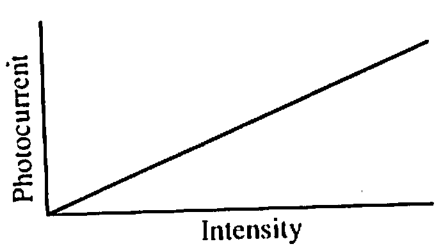
- electric eye
- solar cell
- light meter
- smoke detector

Einstein received a Nobel Prize in 19(for his work on the photoelectric effe Place a zinc plate on an electroscope a charge it negatively. Shine an incand cent light, laser light, and ultravio light on it. Only the ultraviolet light w discharge the electroscope.

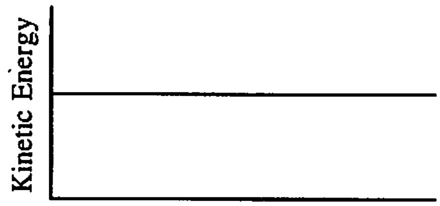
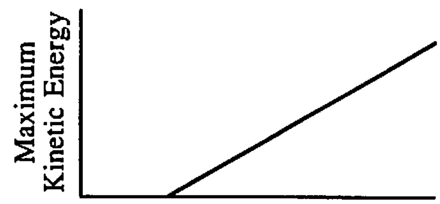
The kinetic energy of the photoelectr actually depends on the frequency of t photon. This effect cannot be explain by the wave theory, but provides e dence for the particle nature of light.

In a region of the spectrum, where photoemission can occur for a material, the rate of emission of photoelectrons is directly proportional to the intensity of the incident radiation.

Plot a photocurrent – intensity graph.



On the basis of the particle model, wh a photon is absorbed by a substance energy of the photon is transferred single electron within the surface.

Content Outline/ Understandings/ Concepts	Discrepancies/ Practical Applications/ Activities	Supplementary Information
The maximum kinetic energy of photoelectrons is dependent only on the frequency of the incident light and the nature of the surface. The maximum kinetic energy of the photoelectrons is independent of the intensity of the incident light.	Plot a kinetic energy -intensity graph. 	The emission of photoelectrons is a random phenomenon. The kinetic energy of the fastest moving electrons can be determined by measuring the retarding voltage necessary to stop the photoelectric current.
For each photo-emissive material there is a minimum frequency called the threshold frequency below which no photoelectrons will be emitted. The energy associated with the threshold frequency is the energy required to remove an electron from the surface of a substance and is called the work function. The maximum kinetic energy of the photoelectrons varies linearly with the frequency of the incident light that produces them.	Plot a maximum kinetic energy – frequency graph for the photoelectrons. 	Light of a frequency below the threshold frequency does not eject photoelectrons from the substance regardless of how great the intensity of the light. According to wave theory, light of any frequency should cause photoelectrons to be emitted, provided the light's intensity is sufficient.
The slope of the kinetic energy versus frequency graph is the same for all photo-emissive surfaces and is equal to Planck's constant.	Determine the slope of a kinetic energy – frequency graph. Compare the results to Planck's constant (6.63×10^{-34} J·s).	
II. THE QUANTUM THEORY The quantum theory was developed to explain phenomena which could not be explained by the classical wave theory of light.		The wave theory is unable to describe the process of radiation absorption observed in the photoelectric effect.
***A. The quantum** Atoms absorb or, if excited, emit electromagnetic radiation only in discrete amounts called quanta. The energy of each quantum is directly proportional to the frequency of the radiation. The constant of proportionality between the energy of a quantum of electromagnetic radiation and its frequency is Planck's constant. $E_{photon} = hf$		In 1905 Einstein proposed that electromagnetic radiation was not only quantized during the process of emission as proposed by Planck, but also remained quantized during transmission and absorption. An analogy that may be used is to compare the wave theory to a hose and water and the quantum theory to buckets of water.
***B. Photon** A photon is a "particle" of light carrying energy and momentum. Photons act individually and their ener-	Given the wavelength of a photon, students are expected to be able to calculate the frequency and energy of the photon.	A photon has energy and has momentum, but a photon is *not* energy or momentum.

Content Outline/ Understandings/ Concepts	Discrepancies/ Practical Applications/ Activities	Supplementary Information
gies are inversely proportional to their wavelength. $$E = \frac{hc}{\lambda}$$		By combining the equations, $E = hf$ an($c = f\lambda$, the relationship between energ) and wavelength is given by $E = hc/\lambda$
***C. Photoelectric equation** The kinetic energy of an ejected photoelectron is equal to the difference between the energy of the incident photon and the work function of the photo-emissive surface. $KE_{max} = hf - W_o$ Substituting $W_o = hf_o$, $KE_{max} = h(f - f_o)$	Unifying theme: Conservation of energy	This equation was formulated by Alber Einstein in 1905. This illustrates conser vation of energy.
D. Photon — particle collisions In a photon – particle collision, the photon energy and momentum decrease, and the particle energy and momentum increase. Both energy and momentum are conserved in this collision. As the energy of the photon decreases, its frequency decreases.	Unifying themes: Conservation of energy, Conservation of momentum	Compton used x-rays for his photon particle collisions in 1922. The Compton Effect is explained in term of the conservation of energy and mo mentum in photon-particle collisions.
***E. Photon momentum** The momentum of a photon is inversely proportional to its wavelength. $$p = \frac{h}{\lambda}$$		Although the photon carries momentun and can exert a force, it does not and can not have rest mass. In any frame of refer ence in space the photon moves with th(speed of light and cannot be at rest.
***F. Matter waves** Moving particles have wave properties. Under ordinary circumstances the wave nature of moving objects is not significant because their momenta are too large (matter wavelengths too small). It is only when the moving particles are on a subatomic scale that their wave properties are observable and important. $$\lambda = \frac{h}{p}$$	Unifying themes: Conservation of energy, Conservation of momentum Practical applications: • electron microscopes	De Broglie made this proposal in 1924 based on his intuitive feeling that natur(is symmetrical and that the dual natur(of light is matched by a dual nature o matter. The de Broglie wavelength should b(computed for a baseball and an electro(to stress that the de Broglie wavelength i insignificant (too small to be diffracte(and detected) for all but subatomic parti cles.
III. MODELS OF THE ATOM **A. The Rutherford model of the atom** On the basis of scattering experiments, Rutherford proposed a model in which the positive charge of an atom, and most of the mass, are considered to be concentrated in	Unifying theme: Fields Students are required to formulate inferences about the contents of a "black box" by making external observations. "Black	Alpha particles directed at a thin metalli foil were observed to be scattered in al directions. The distribution of the parti cles as a function of their scattering an gles was experimentally measured.

Content Outline/ Understandings/ Concepts

a small dense core, called the nucleus of the atom, with electrons widely separated from the nucleus. Most of the atomic volume is space.

1. The alpha particle

   The alpha particle is a helium nucleus which consists of two protons and two neutrons.

2. Alpha particle scattering

   Most of the alpha particles directed at a thin metal foil pass through without being deflected. A very small percentage of particles are scattered through angles ranging up to 180 degrees.

3. Trajectories of alpha particles

   Alpha particles are deflected into hyperbolic paths because of the electric forces (Coulomb forces) between them and the positively charged nuclei of the metal foil.

4. Dimensions of atomic nuclei

   The radii of atomic nuclei are small compared with the radii of their respective atoms.

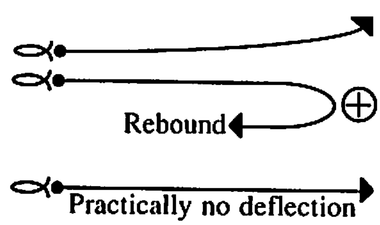
5. Limitations of Rutherford's model

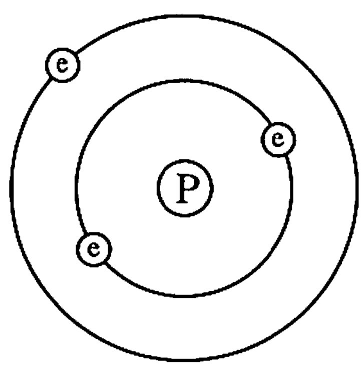
   Rutherford's model did not account for the lack of emission of radiation as electrons move about the nucleus and the unique spectrum of each element.

Discrepancies/ Practical Applications/ Activities

boxes" enable students to develop the skill of modeling. Modeling is extremely important for understanding how scientists developed the modern theory of the atom.

Alpha particle paths





Planetary model of the atom

Supplementary Information

Rutherford confirmed the existence of alpha particles in his "mousetrap" experiment.

Many naturally radioactive substances emit alpha particles. These include radium, radon, polonium, and uranium. The type of nuclear disintegration which results in the emission of alpha particles is called alpha decay.

Energies of particles used in this experiment ranged between 4.5 and 9.0 MeV. This corresponds to velocities from 1.5×10^7 m/s to 2.0×10^7 m/s. The unexpected and significant result of this experiment is the deflection of some particles through very large angles, almost 180 degrees. Since both the nuclei of the foil atoms and the alpha particles are positively charged, the alpha particles experience Coulomb forces of repulsion.

The angle through which the particle is deflected is called the scattering angle. The probability of a head-on collision is very small.

The ratio of the radius of an atomic nucleus to the radius of its atom is between 1:10,000 and 1:100,000.

Electrons moving around the nucleus are accelerated and should radiate energy of changing frequency and eventually collide with the nucleus. Since atoms emit only radiation of specific frequencies and do not collapse spontaneously, Rutherford's model required modification.

Content Outline/ Understandings/ Concepts	Discrepancies/ Practical Applications/ Activities	Supplementary Information

B. The Bohr model of the hydrogen atom

The Bohr model of the hydrogen atom consists of a positively-charged nucleus and a single electron revolving in a circular orbit.

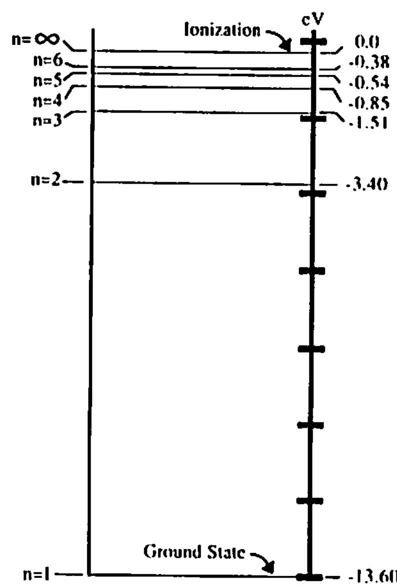
1. Bohr's assumptions

An orbiting electron does not lose energy even though it has an acceleration toward the center.

Only a limited number of specified orbits is permitted. Each orbit represents a particular energy state.

When an electron changes from one energy state to another, a photon with energy equal to the difference between the energies of the two states is emitted or absorbed.

Students should become familiar with the hydrogen energy levels.



Energy levels for the hydrogen atom

Assumptions contrary to classical theory are required to explain the behavior of atoms.

If the optional unit "Motion in a Plane" has not been taught, a brief discussion of circular motion, specifically changing velocity and acceleration toward the center of the circle, will be necessary at this time.

The Bohr model does not provide a fully accurate model for the atom. Quantum mechanics is required for a complete description. However, as an introduction model, the Bohr picture remains useful.

According to classical theory, the electron should lose energy by emitting electromagnetic radiation and spiral into the nucleus.

The permitted orbits are those for which the angular momentum of the electron is an integral multiple of Planck's constant divided by 2π

When an electron goes from one state to another, the change of energy is given by: $hf = E_1 - E_2$ where E_1 and E_2 are the respective energies of the two states and f is the frequency of the radiation emitted.

2. Energy levels

When gas atoms are bombarded by electrons, the gas atoms can accept energy only in discrete amounts.

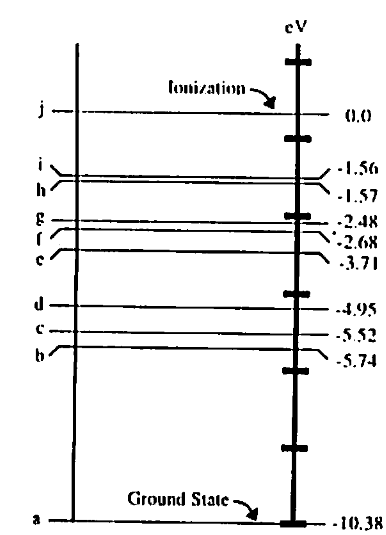
The process of raising the energy of electrons in atoms is called excitation.

Excitation energies are different for different gases.

Excited atoms subsequently release the energy as photons.

Unifying theme: Conservation of energy.

Compare the energy levels of the hydrogen atom with some of the energy levels of the mercury atom.



A few energy levels for the mercury atom

In 1914 J. Franck and G. Hertz further strengthened the concepts of stationary states or fixed energy levels by bombarding vaporized elements such as Hg with electrons. The atoms of gas accepted energy from the electrons only in discrete amounts that agreed with the energy level values of the atoms.

Excitation energies were different for different gases.

Electrons with energies lower than the discrete excitation energies of the gas atoms collided elastically with these atoms and no energy was absorbed.

The Franck – Hertz experiment demonstrates one way of exciting atoms; other methods are thermal excitation, electrical discharge, and electromagnetic excitation.

The energy level diagram shows only a few of the levels for a Mercury atom. For this reason, the levels are labeled a through j.

Content Outline/ Understandings/ Concepts	Discrepancies/ Practical Applications/ Activities	Supplementary Information
a. Ground state The ground state is the most stable state and is the lowest possible energy level.		The minimum energy necessary to remove an electron from the atom is equal to the magnitude of its potential energy minus its kinetic energy.
b. Ionization potential The minimum energy necessary to remove an electron from an atom is called the ionization potential.		The ionization potential is the energy required to remove an outermost electron from its ground state and leave it at rest at infinity, that is, to ionize the atom.
3. Standing waves Standing waves for electrons can exist only at certain distances from the nucleus, which correspond to the discrete energy levels of the atom. An electron in a standing wave about the nucleus will not radiate energy.		A standing wave will occur only when $n\lambda = nh/p$ or $nh/mv = 2\pi r_n$; then Planck's assumption $mvr_n = nh/2\pi$ follows. The number of wavelengths in an orbit for a particular energy level is equal to n. In the ground state, n = 1. All the other states are called excited states because energy must be added to the electron in order to move it to these states. When an atom absorbs energy, an electron moves into orbits with larger radii and into energy levels with higher energy. These standing waves are for the probability function that describes the location of the electron. The electron does *not* travel in a wave-like orbit.
4. Limitations of Bohr model Bohr's model of the atom did not successfully predict other aspects of the hydrogen atom nor can it explain the electron orbits of large atoms having many electrons.		The energy level diagrams for atoms having more than one electron apply to energy states of the whole atom, instead of individual electrons.
5. Atomic spectra Each element has a unique characteristic spectrum since each element has a unique arrangement of orbital electrons.	*Helium was found in the sun before it was found on earth.* Practical applications: • identifying elements in stars • spectroscope • laser	Through a spectral analysis of sunlight, helium was found to exist in the sun before it was detected on earth.
*a. Excitation and emission Atoms excited to energy levels above the ground state emit energy as photons when their electrons fall to lower energy levels. $E_{photon} = E_i - E_f$		If sufficient energy is supplied, the electrons may be excited to one of several energy levels. As each electron returns to the ground state, it can radiate a photon of one particular energy or several photons with energies equal to the energy differences between several internal states.
*b. Emission spectra The energies associated with the lines in an emission spectrum of an element may be determined by using an energy	Quantitative requirements include interpreting energy level diagrams for hydrogen and mercury.	Energy inputs in the range of a few eV can excite electron transitions between outer levels which will emit light when

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level diagram. A visible emission spectrum will appear as bright lines of color on a black background. The emission spectrum formed when excited hydrogen electrons return to the n=2 energy level is called the Balmer series. The Balmer series contains visible lines of red, green and violet.		they return. Input energies in the keV range can excite the innermost electrons which emit x-rays when they return. Other emission spectra for hydrogen are called the Lyman, Paschen, Brackett, and Pfund series.
*c. Absorption spectra An atom will absorb an incident photon only when the photon has an energy equal to the difference between any two given energy levels within the atom.	Practical applications: • Fraunhofer lines in solar spectrum • fluorescence • phosphorescence • fluorescent light Quantitative requirements include interpreting energy level diagrams for hydrogen and mercury.	Phosphorescence occurs when excited electrons delay emitting photons and returning to the unexcited state. As a result, phosphorescent materials can "glow in the dark."
C. Cloud model There is no specific orbit for an electron as it moves about the nucleus. Instead there is a region of most probable electron location called a state. Each electron occupies a state. A state can hold no more than two electrons. The high probability volume for an electron is called an electron cloud.		Schrödinger interpreted the matter waves as probability waves which can only give the probable position of an electron at any given distance, not an exact position. The highest probability is that an electron will be at a distance from the nucleus which agrees with one of Bohr's radii. Since the cloud model is primarily a mathematical model and difficult to visualize, it is beneficial to use a simplified "solar system" model. If the optional topic "Nuclear Energy" is to be discussed, this is an appropriate introduction to it.

Unit Six

Motion in a Plane

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*I. TWO-DIMENSIONAL MOTION AND TRAJECTORIES

The motion of an object traveling in a plane (two dimensions) may be described by separating the motion of the object into x and y components of the vector quantities displacement, velocity and acceleration.

Given the initial velocity (speed and direction) of a projectile in the gravitational field of the Earth, the subsequent motion of the projectile may be described.

Unifying theme: Vectors

Quantitative requirements include determining initial and final vertical, horizontal, and total velocity, range, maximum height, time of flight and time to reach maximum height.

Refer to the equations developed in Unit I, Mechanics, for solving problems in this section.

Practical applications:

- supply drop from an airplane
- seagull dropping clams on the sidewalk

Stress the independence of the horizontal and vertical motions.

Trajectories to be described are limited to projectile motions near the surface of the Earth where g, the acceleration due to gravity, can be considered to be constant at 9.8 meters/second^2 and where there is no appreciable air resistance.

Students should be made aware of the limitations of the friction-free model. The model is inaccurate for the motion of ping-pong balls or bullets. These situations should be studied as typical of problem solving in real world situations.

*A. A projectile fired horizontally

When a projectile is fired horizontally above the surface of the Earth, its initial vertical velocity is zero.

$v_{iv} = 0$

v_x = constant

A ball thrown horizontally at 20 m/s will hit the ground at the same time as another ball dropped from the same height at the same time.

Discuss the effects air resistance has on the actual shape of the flight paths of projectiles.

*B. A projectile fired at an angle

For a projectile fired at an angle with the surface of the Earth, the initial vertical and horizontal components of the velocity may be determined and the motion treated as two separate linear motion problems.

$v_{iv} = v_i \sin \theta$

$v_{ih} = v_i \cos \theta$

Quantitative requirements are limited to projectiles launching and landing at the same height.

Practical applications:

- golf ball
- baseball

Discuss the importance of the axes being perpendicular to each other so that x and y motions are independent; since there is no horizontal force acting on the projectile, the horizontal component of the velocity remains unchanged, and since the only vertical force acting on the projectile is its weight, the vertical component of the velocity changes due to gravitational acceleration. The connection between these independent motions is that both take place simultaneously on the same time scale.

Point out that by separating the vector problem into two separate problems, each can be solved as a linear motion problem. Solving these for both velocity components after the same time interval has elapsed, the separate components can be combined to find the resultant velocity vector at that time. Other quantities can be found similarly.

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It can be shown that, for a given v_o, the maximum range of the projectile will occur when $\theta = 45°$.

II. UNIFORM CIRCULAR MOTION

Uniform circular motion is the motion of an object at constant speed along a circular path.

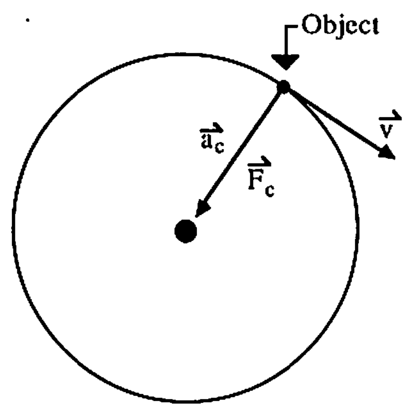
Circular motion should be treated as a problem in dynamics. To understand the dynamics of uniform circular motion, one should know the frame of reference from which one observes the motion. It should be the inertial or Earth frame of reference, not the accelerated frame of reference, the frame of reference of the object moving in the circular path. If one places oneself in the accelerated frame of reference, one will experience a force, commonly referred to as a centrifugal force, which acts away from the center of motion.

*A. Centripetal acceleration

An object undergoing uniform circular motion has a centripetal acceleration directed toward the center of curvature.

Centripetal acceleration is a vector quantity. The magnitude of the centripetal acceleration is directly proportional to the square of the speed and inversely proportional to the radius of the path.

$$a_c = \frac{v^2}{r}$$



Centripetal acceleration arises from the change in direction of the velocity. Point out that this acceleration must be perpendicular to the velocity if the magnitude of the velocity is constant; there must be no component of acceleration parallel to the velocity.

*B. Centripetal force

The force which causes the centripetal acceleration is centripetal force. It is a vector quantity directed toward the center of curvature. Its magnitude is directly proportional to the product of the mass of the object being accelerated and the centripetal acceleration.

$$F_c = \frac{mv^2}{r}$$

The centripetal force is the net force acting on the body. The body maintains its constant speed because there are no tangential forces. It is not in equilibrium.

Practical applications:
- amusement park rides
- satellite
- car rounding curve

A rotating space station may have artificial gravity.

Derive $F_c = mv^2/r$ from Newton's 2nd law, $F = ma$, and centripetal acceleration.

To clarify the dynamics of uniform circular motion, use free body diagrams of the forces and everyday situations in which centripetal force and acceleration are observed and experienced.

Friction provides the centripetal force that keeps a car on the road as it goes around a curve. Discuss why race-car tracks and highways have banked curves.

Point out that the object would move tangentially in a straight line in the absence of the centripetal force, which must be applied to change the direction of the velocity of the mass.

III. KEPLER'S LAWS

A. Kepler's first law

The path of each planet about the Sun is an ellipse with the Sun at one focus.

An ellipse is a closed curve such that the sum of the distances from any

Neptune is sometimes further from the sun than Pluto.

It is interesting to note that the force that causes an object to move in an ellipse, as well as the path of any other conic section (parabola, hyperbola or circle) is an inverse square force.

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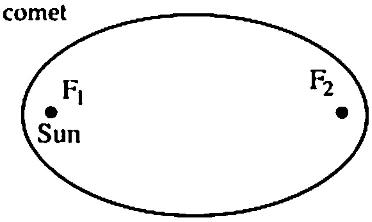
point P on the curve to two fixed points (called the foci, F_1 and F_2) remains constant. A circle is a special case of an ellipse in which the two foci coincide, at the center of the circle.

Practical applications:

- planetary motion
- comet



Of all the planets, Pluto has the most elliptical orbit. Venus and Neptune have orbits that are closest to a circle.

B. Kepler's second law

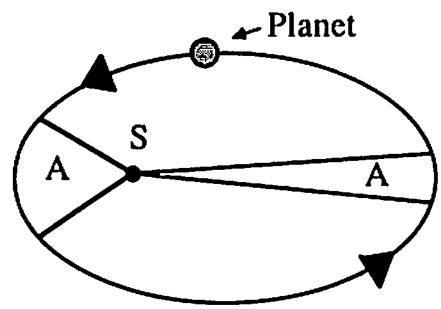
Each planet moves so that an imaginary line drawn from the Sun to the planet sweeps out equal areas in equal periods of time.

As a planet moves closer to the sun, the planet's potential energy decreases and its kinetic energy increases, resulting in a change in speed. Most comets have very elliptical orbits so that these changes in speed are more pronounced.

Unifying theme: Conservation of energy

Discuss the changes in centripetal acceleration as a satellite follows an elliptical path.

The Sun is closest to the Earth in January; furthest away in July.



C. Kepler's third law

The ratio of the mean radius of orbit cubed to the orbital period of its motion squared is the same for all planets.

$R^3/T^2 = K$, where K is a constant for this ratio. K *is not* a universal constant; it is a constant for satellites of a particular body being orbited, e.g., the sun, a star, a planet, etc.

Quantitative treatment of Kepler's third law is not required.

Make it clear that the constant K depends on the mass of the body being orbited. K for objects orbiting the earth is 1.02×10^{13} m^3/s^2; for objects orbiting the sun, K is 3.35×10^{18} m^3/s^2.

As the mass of an object being orbited decreases, K decreases.

Newton's Law of Universal Gravitation together with uniform circular motion leads to Kepler's Third Law if the assumption is made that the orbit of the planet is circular. (The orbits of the planets except for Mercury and Pluto are very close to circular.) For a planet in a circular orbit, of radius equal to the real planet's mean radius, the centripetal force is provided by the gravitational force:

$F_c = Gm_pm_s/R^2 = m_p v^2/R$

Substituting $v = 2\pi R/T$

Then $\frac{Gm_s}{R^2} = \frac{(2\pi R/T)^2}{R} = 4\pi^2R/T^2$

Or $\frac{R^3}{T^2} = \frac{Gm_s}{4\pi^2}$

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IV. SATELLITE MOTION

A satellite is defined as a smaller body which revolves around a larger one. Satellites of the Sun include the planets. Satellites of the Earth are the Moon and human-made objects placed in orbits about the Earth.

The orbits of satellites around the Earth are frequently circular.

If the speed of a satellite decreases, such as by the drag of the atmosphere, it will spiral back toward Earth. If the speed of a satellite exceeds escape velocity, it will leave Earth orbit.

Satellites are falling around the Earth.

Unifying themes: Vectors, Fields, Conservation of energy

Practical applications:

- space shuttle
- Moon
- apparent "weightlessness" of an astronaut

Practical applications:

- skylab
- meteor

Point out that objects such as the Moon and the Earth revolve around their center of mass. The center of mass of the Earth-Moon system lies at about 2/3 radius of the Earth. Other examples should be used.

For the Apollo astronauts to land on the Moon, their ship had to first achieve escape velocity for the Earth. On leaving the Moon, their ship had to reach the Moon's escape velocity. Escape velocity for the Earth is 11 km/s.

Pioneer 10 crossed Neptune's orbit in 1983, 11 years after being launched from Earth. As it passed Jupiter, Pioneer 10 used Jupiter's gravitational field to speed up enough to escape from the solar system.

A. Geosynchronous orbits

A geosynchronous orbit is one in which the period of the satellite is the same as the period of the Earth's rotation around its own axis. In a geosynchronous orbit, the satellite always remains in the same position over a point on the Earth's equator.

B. Artificial satellites

The radius of orbit of a human-made satellite of the Earth may be determined by equating R^3/T^2 for the Moon and R^3/T^2 for the satellite.

Practical applications:

- communication satellite
- weather satellite

To determine the radius for a geosynchronous orbit of a satellite, R_s, substitute $T_s = 8.64 \times 10^4$s = 24 hours. The value obtained will be as measured from the center of the Earth, approximately six Earth radii. To determine the distance of the satellite from the Earth's surface, subtract the radius of the Earth, 6.38×10^6 meters.

Using Kepler's Third Law,

$R_m^3/T_m^2 = R_s^3/T_s^2$

Time for Moon's orbit = 2.36×10^6 seconds, and radius of Moon's orbit = 3.84×10^8m.

$R_m^3/T_m^2 = (3.84 \times 10^8)^3/(2.36 \times 10^6)^2 = R_s^3/T_s^2 = R_s^3/(8.64 \times 10^4)^2$

$R_s^3 = 7.59 \times 10^{22}\text{m}^3$

$R_s = 4.23 \times 10^7\text{m}$

Unit Seven

INTERNAL ENERGY

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I. TEMPERATURE Temperature is an indication of how hot or cold something is with respect to a chosen standard. Temperature is a scalar quantity.	Practical applications: • bimetallic strip • digital thermometer • thermocouple	A discussion of the various types of thermometers is appropriate. In terms of the microstructure of matter, temperature is proportional to the average Kinetic energy, that can be exchanged between particles, of the particles in an object.
A. Absolute temperature Absolute temperature is directly proportional to the average kinetic energy of random motion of the molecules of an ideal gas.	Requirements are limited to the recognition, interpretation, and use of graphs of average kinetic energy versus temperature.	An ideal gas is one which consists of perfectly elastic particles of negligible size which exert no forces on each other, except during collisions.
1. Absolute zero At absolute zero no thermal energy can be transferred to another object.		By extrapolation of the relationship between the absolute temperature and the average kinetic energy of the molecules of an ideal gas, absolute zero would appear to represent zero kinetic energy, or the absence of all molecular motion. However, according to modern theory, at absolute zero the molecules of a substance have a finite amount of energy, known as the zero-point energy. In theory and in practice, absolute zero is not attainable by a finite series of processes.
B. Temperature scales Temperature measurements are commonly referred to arbitrarily selected fixed temperatures, which are called fixed points and are readily reproducible.	Practical applications: • weather report	The expression "centigrade temperature" should be avoided.
1. Celsius On the Celsius scale the freezing point of water is 0 degree and the boiling point is 100 degrees at standard pressure.		In 1954 the size of the degree was set by the General Conference of Weights and Measures. The triple point of water, (the unique temperature at which water can co-exist as a solid, liquid and gas) was selected as the standard, fixed point of thermometry and defined as 273.16 K or 0.01°C. The value of 273 K is satisfactory for class use.
*2. Kelvin On the kelvin scale absolute zero is the zero point.		

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The kelvin, K, is the SI unit of temperature. It is a fundamental unit. The kelvin temperature is equal to the sum of the celsius temperature and 273.	Practical applications: • cryogenics • superconductor	
II. INTERNAL ENERGY & HEAT Internal energy is the total kinetic and potential energies associated with the motions and relative positions of the molecules of an object, apart from any kinetic or potential energy of the object as a whole.	Unifying themes: Conservation of energy Requirements are limited to the recognition, interpretation, and use of heating-cooling curves. Practical applications: • thermal pollution • OTEC energy system	An increase in the internal energy of an object can result in a variety of changes in the motions and positions of the atoms. Energy used in doing work against friction is converted into internal energy.
Heat is energy that is transferred from a warm body to a cold body because of the temperature difference between them.	*Even at 0°C, outside air can be used to heat your home.* *There is more heat energy in the Arctic Ocean during the winter than in a boiling cup of water.*	The total internal energy of an object depends on its temperature, mass, material, and phase. Stress the difference between heat and temperature.
Heat is a scalar quantity. The joule, J, is the SI unit of heat. 1. Mechanical equivalent of heat Heat and mechanical energy are both forms of energy; therefore, they can be measured in the same units.	Practical applications: • driving a nail into wood	The kilocalorie is also a unit of heat energy. One kilocalorie is equivalent to 4186 joules. Performing calculations with kilocalories is not required.
***A. Specific heat** The specific heat of a substance is the quantity of heat required to raise the temperature of a unit mass of the substance one Celsius degree. $Q = mc\Delta T_c$ The energy absorbed or liberated in a temperature change does not produce a change in phase. It does, however, produce a change in the average kinetic energy of the molecules.	Practical applications: • crust of pizza cools faster than the topping • water's modifying effect on climate • water-cooled engine	The specific heat of a material depends on temperature. However, at ordinary temperatures and over ordinary temperature intervals, specific heats can be considered to be constant. Specific heat of water is 4.19×10^3 J/kg·C° = 4.19 kJ/kg·C°.
B. Exchange of internal energy *1. Conservation of internal energy When there is an exchange of internal energy and no conversion to other forms of energy, the total internal energy of the system remains constant.	Unifying theme: Conservation of energy Quantitative requirements include determining the final temperature when two substances are mixed, assuming a closed system. Practical applications: • solar energy storage	The term "phase" is used instead of "state" to avoid confusion with other conditions, such as state of equilibrium.

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2. Change of phase During a change of phase of a crystalline substance there is a change in internal energy but no change in temperature. The energy absorbed or liberated in a change of phase does not change the average internal kinetic energy and does not produce a change of temperature. It does, however, produce a change in the molecular potential energy associated with the bonds between molecules.		The temperature of a non-crystalline solid, such as glass, does not remain constant during melting and freezing.
*a. Heat of fusion The heat of fusion is the amount of heat required to change one kilogram of a substance at its melting point from the solid to the liquid phase with no change in temperature. $Q_f = mH_f$ The same amount of energy is liberated when an equal mass of the substance at its freezing point freezes.	Practical applications: • freezing ice cream • melting snow	When ice cream is frozen using an ice-salt mixture, it is the melting of the ice that takes the heat from the cream mix.
*b. Heat of vaporization The heat of vaporization is the amount of heat required to change one kilogram of a substance at its boiling point from the liquid to the gaseous phase with no change in temperature. $Q_v = mH_v$ The same amount of energy is liberated when an equal mass of the substance at its condensation point condenses.	Practical applications: • refrigerators • heat pumps	The heat of vaporization is a constant only when no external work is done.
c. Factors affecting boiling and freezing points of water. (1) The effect of salt A dissolved salt lowers the freezing point of water. A dissolved salt raises the boiling point of water.	Practical applications: • salt on icy roads *When salt is added to boiling water, the water stops boiling.*	
(2) The effect of pressure Increased pressure lowers the melting point of ice. Increased pressure raises the boiling point of water.	*It will take longer to bake a cake on the top of Whiteface Mountain than on the shore of Lake Ronkonkoma.*	Melting and refreezing due to pressure changes is called regelation. Pressure tends to force the materials into

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You can hold a flask of boiling water in your bare hand.

Practical applications:

- making a snowball
- pressure cooker

the state which occupies the smallest volume.

III. KINETIC THEORY OF GASES

Gases are composed of molecules in constant random motion. In gases of low density, the average distance of separation of molecules is large in comparison with their diameters, and the total actual volume of the gas molecules is small in comparison with the volume occupied by the gas.

The forces between molecules in a low density gas are negligible except when the molecules collide.

Collisions between gas particles will usually result in a transfer of energy between particles, but the total energy of the system remains the same.

A gas that would conform strictly to this model would be an ideal gas. This model does not exactly represent any gas under all conditions of temperature and pressure. A general rule is that a gas made up of molecules with only a few atoms each, well above its boiling point can be considered to be ideal.

A. Pressure

Pressure exerted by a gas is due to collisions of gas molecules with the walls of the container.

Air can cause a sealed metal can to collapse.

Practical applications:

- balloon
- breathing
- vacuum cleaner
- drinking soda through a straw

Standard temperature and pressure (STP) of a gas are defined as 0°C (273 K) and 760 mm of mercury (760 torr) or 1 atmosphere of pressure.

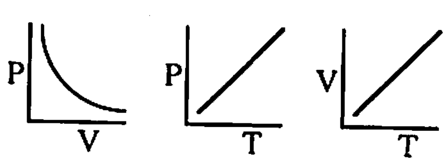
One atmosphere is a pressure of 1.01×10^5 N/m^2 or 101 kilopascals (101 kPa).

The pascal is the SI unit of pressure.

1 Pa = 1 N/m^2

B. Gas laws

The product of the pressure and volume of an ideal gas is directly proportional to the product of the number of molecules of the gas and their absolute temperature.



Requirements include the recognition, interpretation, and use of graphs and simple proportions involving the relationships among pressure, volume, and temperature for a fixed mass of gas.

Practical applications:

- cartesian diver
- blowing up a balloon

This is a statement of the ideal gas law represented as PV = nRT.

As divers rise to the surface, they must expel air from their lungs because the air is expanding with decreasing pressure.

For a fixed mass of gas:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

The ideal gas law incorporates the gas laws of Boyle and Charles. A discussion of these laws is appropriate.

IV. LAWS OF THERMODYNAMICS

A. First law

The heat added to a system is equal to the sum of the increase in internal energy of the system and the external work done by the system.

Unifying theme: Conservation of energy

Practical applications:

- bicycle pump
- cylinders in an auto engine

A system is a specific material or group of objects, such as an automobile, the moon and the earth, or the entire solar system.

Discuss adiabatic processes, such as adiabatic temperature changes within an air mass.

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B. Second law		
Unless external work is done to produce the effect, heat cannot flow from a cold region to a hotter region.	Practical applications: • heat pump • refrigerator	Discuss heat engines, devices whicl convert heat into work or mechanical energy.
Entropy is a quantitative measure of the disorder of a system. There is a tendency in nature to proceed toward a state of greater disorder. The entropy of the universe is steadily increasing.	Identify the second law of thermodynamics in physical examples. Practical applications: • an object breaking • ice changing into water • a house cooling off in the winter • the sun emitting energy	Emphasize the inefficiency of machine due to heat loss. Discuss the uses of insulation as well as improved designs an methods for recovering and using exces heat.
C. Third law		
It is impossible by any set of finite operations to reduce the temperature of a system to absolute zero.		Ordinary helium $^{4}_{2}He$ liquefies at 4.2 K The lowest temperature that has bee reached is 0.7 K.

Unit Eight

Electromagnetic Applications

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I. TORQUE ON A CURRENT-CARRYING LOOP

A current-carrying loop of wire experiences a torque in a magnetic field.

The direction of the torque tends to turn the loop so that the field due to the current is parallel to the external field. The torque is proportional to the current in the loop.

When a current-carrying loop of wire is placed in a magnetic field, the loop will rotate.

Unifying themes: Fields, Vectors

Practical applications:

- electric motors
- meters

Review the force on a current-carrying conductor.

A torque may be defined simply as a force acting at a distance causing an object to rotate.

The torque results from the fact that as the current circulates in the loop it is moving in opposite directions on either side of the loop so the force on one side of the loop is opposite to the force on the other side of the loop.

A. Meters

1. Galvanometer

A galvanometer is a device used to measure weak electric current.

A galvanometer has a coil placed in a uniform field produced by a permanent horseshoe magnet. This coil is free to rotate against a spring. The degree of deflection of the coil is directly proportional to the current in the coil.

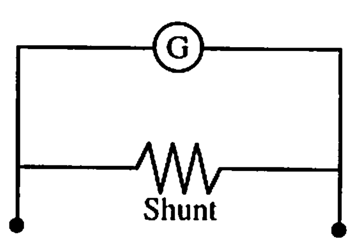
Modern digital or electronic meters are based on principles different from those described here.

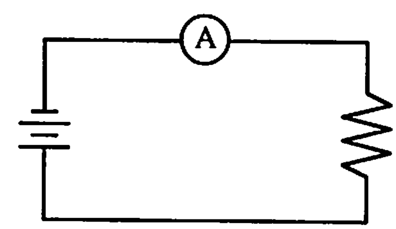
2. Ammeter

An ammeter is a modified galvanometer used to measure larger currents. In an ammeter a shunt is placed in parallel with the coil allowing most of the current to bypass the coil. The resistance of the shunt is very small compared to the resistance of the coil. Decreasing the shunt resistance increases the maximum reading on the meter.

The low resistance of the shunt makes the internal resistance of

An ammeter is placed in series with the circuit element being measured.





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the ammeter very small so that the potential drop across the meter has a negligible effect on the circuit being measured.

3. Voltmeter

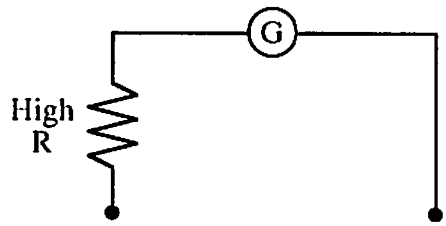
A voltmeter is a modified galvanometer used to measure potential difference.

In a voltmeter a high resistance wire is connected in series with the coil.

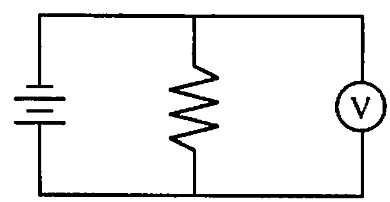
Increasing the series resistance increases the maximum reading on the meter.

The high resistance of the series resistor makes the internal resistance of the voltmeter very high so that it draws very little current and has a negligible effect on the circuit being measured.

A voltmeter is placed in parallel across the element whose potential difference is being measured.



Calculate the series resistance for voltmeters. This will not be subject to testing.



B. Motors

An electric motor is a device that converts electrical energy into rotational mechanical energy. The torque on a current carrying-coil in a magnetic field is the basis of the electric motor.

1. Iron core

In a practical motor the coil is wound on an iron core causing the torque to become very large. Iron is a permeable material that will concentrate and strengthen the magnetic field passing through it.

2. Split-ring commutator

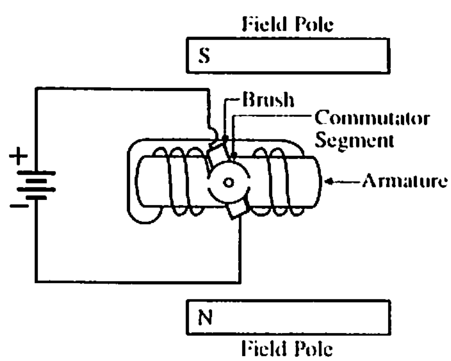
A split-ring commutator is used to reverse the DC current in the armature coil after each half-rotation so that the torque is always in the same direction.

3. Back EMF

An operating electric motor will produce an induced EMF, electromotive force, in the armature coil which will oppose the applied potential difference and reduce the current in the armature.

Practical applications:

- hand tools
- appliances



Unifying theme: Conservation of energy

In a practical motor, there are several coils to take advantage of the fact that the torque is maximum when the plane of the coil is parallel to the field.

A stalled motor will overheat and possibly catch fire because of the lack of back Emf.

The back Emf arises because the armature coil is rotating in an external magnetic field and is therefore acting as a

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generator, whose induced potential difference must oppose the applied potential difference that provides the driving current. This is known as Lenz's Law.

II. ELECTRON BEAMS

A. Thermionic emission

Thermionic emission is the ejection of electrons from a hot surface.

As the temperature of the surface increases, the rate of electron emission increases.

Unifying themes: Fields, Vectors

Practical applications:

- vacuum diode
- TV picture tube

At high temperatures, the electrons on the surface have high kinetic energies and can "boil off". This is analogous to the molecules of a boiling liquid.

Thermionic emission was discovered by Edison and was originally known as the "Edison Effect."

A space charge will be developed around incandescent objects which will impede the continued emission of electrons.

B. Electron beams in an electric field

An electric field may be used to accelerate electrons.

Electrons located between oppositely charged parallel plates experience a constant unbalanced force which causes the electrons to accelerate toward the positive plate.

If the potential difference between the plates increases, the acceleration of the electrons increases.

Using $V = W/q$ and $KE = \frac{1}{2}mv^2$, calculate the final velocity of the electrons.

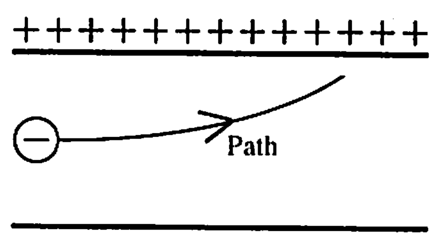
*C. Control of electron beams

Electron beams are controlled by electric and/or magnetic fields.

In an electric field, the beam is deflected parallel to the field.

Practical applications:

- television set



In a magnetic field the beam is deflected by a force which is perpendicular to both the beam and the field. The force on each charge in the beam is directly proportional to the magnitude and velocity of the charge and the strength of the magnetic field.

$$F = qvB$$

An appropriate hand rule should be used to determine the direction of deflection.

The force on a current-carrying conductor arises from the forces on the individual electrons in the wire.

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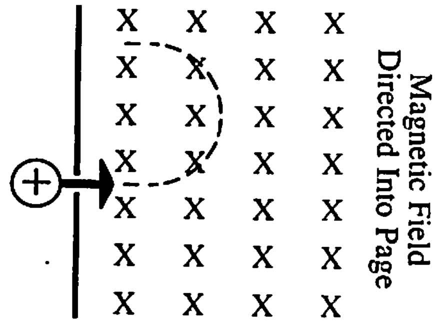
The magnetic force will cause the electron beam to travel in a curved path.



$F = qvB$ is a centripetal force equal to mv^2/r. Using this relationship, the radius of the path or mass of the particle can be found.

1. A cathode ray tube is an evacuated glass tube containing a source of electrons at one end, a fluorescent screen inside the surface at the other end, and two pairs of deflecting plates in between.

   The uniform electric field between the oppositely charged plates controls the direction of the electron beam.

   The electron beam produces a fluorescent spot of light when it strikes the screen. The brightness of this spot is directly related to the intensity of the electron beam striking the screen.

Practical applications:

- television
- computer monitor
- oscilloscope screen

D. **Other charged particle beams**

1. Mass spectrometer

   A mass spectrometer is a device used to determine the masses of individual atoms.

   An element in the gaseous phase is bombarded with electrons causing one or more electrons to be removed from the atoms of the element. The resulting positive ions are subjected to magnetic and electric fields.

   The charge to mass ratio of ions may be determined by measuring the radius of the circular path that the ions travel.

   If the charge on the ion is known, then its mass can be calculated. This is a common method of separating the isotopes of an element and determining their masses.

In a mass spectrometer, a device called a "velocity selector" is used to project particles into the magnetic field and prevent variations in the particle velocities.

Since the mass of an electron is very small compared to that of an atom, the mass of an ion is very nearly equal to the mass of its atom.

To determine q/m:

From the electric field:

$$W = Vq = \tfrac{1}{2}mv^2 \text{ and } v^2 = \frac{2Vq}{m}$$

From the magnetic field:

$$F = qvB = \frac{mv^2}{r} \text{ and } \frac{q}{m} = \frac{v}{Br}$$

Substituting for v: $\frac{q}{m} = \frac{2V}{B^2r^2}$

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2. Mass of the electron The Millikan oil drop experiment determined that an electric charge is always an integral multiple of an indivisible unit of charge called the elementary charge. Since the charge to mass ratio of the electron was known, the mass of the electron could be calculated.		Thomson determined e/m for electrons in 1897. Millikan performed his series of measurements between 1909 and 1913.
3. Particle accelerators A particle accelerator is a device used to accelerate charged particles to speeds approaching the speed of light by subjecting the particles to a large potential drop or a series of repeated smaller potential drops. The charged particles bombard nuclei to provide information about the structure of nuclei and subatomic particles.	Practical applications: • Van de Graaff generator • cyclotron • synchrotron • linear accelerator	Examples of particle accelerators include the Van de Graaff generator, using a single large potential drop and the cyclotron, synchrotron, and linear accelerator using repeated smaller potential drops.
III. INDUCED VOLTAGE A changing magnetic field can induce a potential difference in a conductor.	Practical applications: • magnetic levitation	The basic principle for the operation of transformers and induction coils is electromagnetic induction. Trains in the future may use magnetic levitation to actually move along slightly above the track, dramatically increasing possible speeds.
***A. Magnitude and direction of an induced potential difference** For a straight conductor, oriented perpendicular to the field and moving perpendicular to the field and to the conductor, the magnitude of an induced electromotive force is directly proportional to the flux density, the length of the conductor in the field, and the speed of the conductor relative to the flux. $V = Blv$ If the conductor is part of a complete circuit, the induced potential difference produces a current in the circuit. An induced current produces a magnetic field whose effect opposes the change that produced it. This is an example of the Law of Conservation of Energy and is known as Lenz's Law.	The direction of the induced potential difference may be determined by an appropriate hand rule.	

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B. Generator principle

A conducting loop rotated in a uniform magnetic field experiences a continual change in the total magnetic flux linkage. This change induces a potential across the ends of the loop which alternates in direction and varies in magnitude between zero and a maximum.

Turning a loop of wire in a magnetic field produces an electric current.

Unifying theme: Conservation of energy

Practical applications:

- power plant

Use of generators in power plants should be discussed, including alternative energy sources for running the generators.

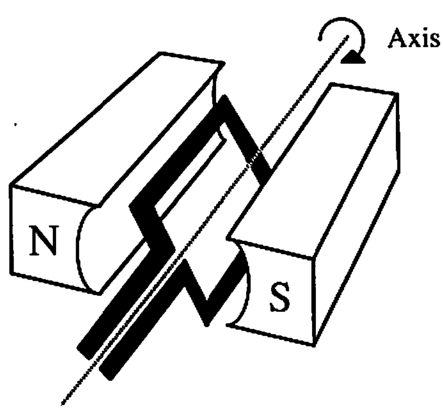
The magnitude of the induced potential difference and induced current vary sinusoidally with time.

The induced potential difference is zero when the velocity of the wire and the direction of the magnetic field are parallel.

The induced potential difference is a maximum when the velocity of the wire and the direction of the magnetic field are perpendicular.

When the loop is connected to an external circuit to form a complete circuit, the induced potential difference causes a current in the circuit. Since the induced potential difference is alternating, the current is an alternating current.

An alternating current is a current that reverses its direction with a regular frequency.



The magnitude of the induced potential difference is proportional to the component of the velocity perpendicular to the field and the intensity of the magnetic field.

Set up a hand generator and vary the resistance. As the resistance increases, the generator becomes easier to turn.

Electric current used in the home is an alternating current.

One of the reasons alternating current was adopted as the standard was that the voltage could easily be changed and line losses reduced by transmitting electric power at high voltage so current can be low.

*C. Transformers

A transformer is a device used to change the voltage of an alternating current into a larger or smaller voltage of alternating current.

A transformer consists of a primary and a secondary coil wound on an iron core. A continually changing current in the primary coil produces a continually changing magnetic field that induces an alternating voltage in the secondary coil.

1. Voltage relationship

   The ratio of the number of turns on the primary coil to the number of turns on the secondary coil of a transformer is equal to the ratio of the voltage across the primary coil to the voltage induced in the secondary coil.

$$\frac{N_p}{N_s} = \frac{V_p}{V_s}$$

Practical applications:

- Step-up transformers: fluorescent light, neon light, x-ray machine
- Step-down transformers: electric toy racing car, electric toy train, doorbell, furnace thermostat

The transformer consists of a primary coil whose changing current changes the magnetic flux through another or secondary coil, inducing an Emf in it.

Transformers are used in a variety of electrical devices.

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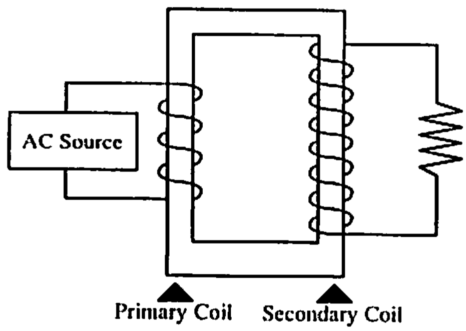
2. Power relationship

A transformer will transfer energy from the primary coil to the secondary coil if the secondary coil is connected in a complete circuit.

Power output from the secondary coil can never exceed the power input to the primary coil.

Unifying theme: Conservation of energy



PCB's are important for helping to distribute the heat in a transformer. Their high heat transfer efficiency is due to their massive, stable molecule, their high boiling point, and their high specific heat. Because the molecule is so stable, environmental problems are created.

In a 100% efficient transformer, the power input to the primary coil is equal to the power output from the secondary coil.

$$V_p I_p = V_s I_s$$

The efficiency of the transformer is equal to the ratio of the power output from the secondary coil to the power input to the primary coil.

$$\% \text{ efficiency} = \frac{V_s I_s}{V_p I_p} \times 100$$

Transformers are used to convert the 220 volt power common in most of the world to 110 volts so that travelers from the United States may use their electric shavers and other electrical appliances.

The main source of energy loss in transformers is due to heat generated by eddy currents induced in the core. Cores are laminated to reduce eddy currents.

Most commercial transformers operate with efficiencies close to 99%.

D. Induction coils

Induction coils are electric devices used to induce time-varying potential differencesfrom DC potential differences. The changes in current are caused by turning the primary current on and off with an electromechanical switch or a solid state circuit.

Practical applications:

- ignition system in a car

Induction coils are used in automobile engines and small gasoline engines to provide a spark for ignition of the fuel.

IV. THE LASER

The laser is a device that generates electromagnetic radiation by stimulating the emission of photons from atoms.

Laser light is nearly coherent.

A beam of light may replace the scalpel used in surgery.

Practical applications:

- bar-code scanning system
- videodisc player
- holography

Laser is an acronym for light amplification by stimulated emission of radiation.

The distance from the Earth to the Moon was measured when a laser pulse was reflected back to Earth by a mirror on the Moon's surface.

The helium-neon laser most commonly found in classrooms is a continuous beam gas laser. High voltage induces an electrical discharge within the gas, exciting helium atoms by collisions with the electrons. The helium atoms in turn collide with neon atoms, exciting them. The neon atoms then emit photons in the visible red region.

Safety precaution: avoid having the direct beam or reflected beam of the laser enter the eye.

Unit Nine

GEOMETRICAL OPTICS

Content Outline/ Understandings/ Concepts	Discrepancies/ Practical Applications/ Activities	Supplementary Information
I. IMAGES An image is formed where light rays originating from the same point intersect on a surface or appear to intersect for an observer.		
A. Real image Real images are formed when light rays from a common point pass through an optical system that causes them to converge and intersect at a point.	Practical applications: • camera • slide and movie projectors	Real images can be projected onto a screen.
B. Virtual image Virtual images are formed when the light rays from a common point pass through, or are reflected by, an optical system that causes them to diverge and appear to come from a single point.	Practical applications: • plane mirror • magnifying glass • concave lens • convex mirror	A virtual image appears to form where an image cannot possibly exist because rays do not actually intersect at the image point. Virtual images cannot be formed on a screen.
II. IMAGES FORMED BY REFLECTION		
A. Images formed by a plane mirror The image formed by a plane mirror is virtual, erect, reversed, and the same size as the object. The object and image distances from the mirror are equal.	*To view the entire body of a person, a mirror that is half the person's height is all that is needed.* Draw ray diagrams for plane mirrors. Practical applications: • toy periscope • kaleidoscope	A lab exercise that uses ray tracing to locate the image formed by a plane mirror should be performed. A kaleidoscope has multiple plane mirrors at angles to each other. Real periscopes use prisms.
B. Images formed by a spherical mirror The reflecting surface of a spherical mirror is a segment of a sphere. Rays parallel to the principal axis are reflected by the mirror and meet at a point called the principal focus. The center of curvature is twice the focal point. Rays directed toward the center of curvature of a spherical mirror strike the mirror normal to the surface and	*You can see the World Trade Center in a pocket mirror.* Practical applications: • amusement park mirrors	Early refracting telescopes had serious problems with chromatic aberration. Newton used spherical mirrors to developed a reflecting telescope to eliminate this problem. A spoon can be used to demonstrate image formation by concave and convex mirrors.

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are reflected normal to the surface.

*1. Concave mirrors

A concave mirror causes parallel light rays to converge.

A concave mirror causes light rays parallel to the principal axis to reflect and converge at the principal focus.

Rays passing through the principal focus and incident on a concave mirror are reflected parallel to the principal axis.

Rays passing through the center of curvature of a concave mirror strike the mirror normal to the surface and are reflected normal to the surface.

The size and location of the image can be calculated from the focal length of the mirror and the position and size of the object.

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

and

$$\frac{S_o}{S_i} = \frac{d_o}{d_i}$$

For a concave mirror, the focal length is positive. Real image-distances are positive and virtual image-distances are negative.

Draw ray diagrams for concave mirrors.

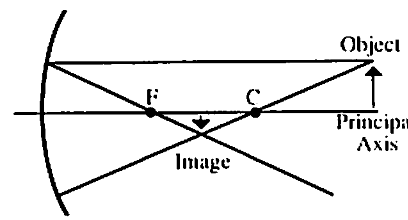
Practical applications:

- spotlight
- searchlight
- headlight
- reflecting telescope
- shaving and makeup mirror
- solar collector

Requirements include describing images when objects are placed beyond 2f, at 2f, between 2f and f, at f, and less than f.

Concave mirrors are used to focus the sun's rays in some devices used to collect solar energy.

In ray diagrams, use solid lines for real light rays and dashed lines for virtual light rays.



This equation is an approximation derived for cases where the arc length is small compared to the radius of curvature.

* 2. Convex mirror

A convex mirror causes parallel light rays to diverge.

Rays parallel to the principal axis are reflected from a convex mirror and appear to originate from a virtual focal point on the opposite side of the mirror. For a convex mirror, the focal length is negative.

If the emergent rays that have originated from the same point on the object are projected backward, the point from which they appear to be diverging is the location of the virtual image.

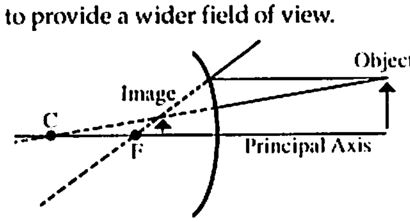
When viewed through some side-view mirrors, objects are closer than they appear.

Draw ray diagrams for convex mirrors.

Practical applications:

- security mirror in a store

Some outside mirrors on cars are convex to provide a wider field of view.



When a bundle of rays which originated at a point source passes through an optical system and is incident on the eye as a diverging cone of rays and then focused on the retina, the observer interprets the rays as coming from the vertex of the diverging cone.

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Only virtual images, smaller than the objects, are formed by a convex mirror. Virtual image-distances are negative.	Quantitative requirements include application of the relationships $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$ and $\frac{S_o}{S_i} = \frac{d_o}{d_i}$	
3. Spherical aberration Spherical aberration results when all of the rays do not come to a focus at the principal focus.	Practical applications: • parabolic mirror	Spherical aberration in a mirror results from rays that reflect near the edges of the mirror. Spherical aberration can be corrected by making the mirror parabolic.

III. IMAGES FORMED BY REFRACTIONS

A. Converging lenses

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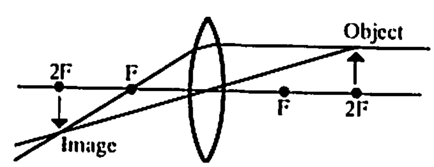
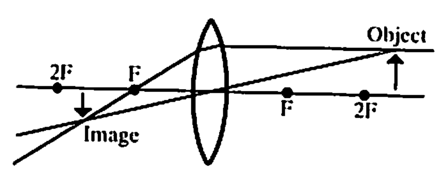
A converging lens (convex) is a lens that is thicker at the middle than at the edges and converges parallel rays of light.	*Slides are put into a projector upside down and backwards.* Practical applications: • camera • projector • the eye • eyeglasses • microscope • magnifying glass	Converging lenses are used to correct for farsightedness. The eye can change its shape and, therefore, its focal length to focus on objects at different distances.
1. Real and virtual images A converging lens can form both real and virtual images.	Draw ray diagrams for converging lenses.	The formation of a virtual image by a magnifying glass should be discussed. Develop an understanding of the size and location of the image as the object is brought towards a converging lens.
Rays parallel to the principal axis and passing through a converging lens will converge at a point known as the principal focus. Rays passing through the optical center of a lens emerge travelling parallel to their original direction. Rays which pass through the principal focus before entering a converging lens emerge parallel to the principal axis.	Requirements include describing images for objects placed beyond 2f, at 2f, between 2f and f, at f, and less than f.	 
*2. Size and distance of images The size and location of the image can be calculated from the focal length of the lens and the position and size of the object.		Specific reference should be made to applications of several cases such as the telescope, microscope, camera, projector, magnifying glass, etc. Magnification comparisons can be made

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$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$\frac{S_o}{S_i} = \frac{d_o}{d_i}$$

For a converging lens, the focal length is positive. Real image distances are positive, and virtual image distances are negative.

by finding the ratio of image size to object size.

The relationship $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$ holds only for thin lenses.

***B. Diverging lenses**

A diverging (concave) lens is a lens that is thinner at the middle than at the edges and diverges parallel rays of light.

For a real object, a diverging lens can produce only a virtual, smaller image on the same side of the lens as the object. Rays parallel to the principal axis leave the lens such that they appear to have originated from the virtual focal point on the side of the lens from which the light was incident.

For a diverging lens, the focal length and image-distance are negative.

Draw ray diagrams for diverging lenses.

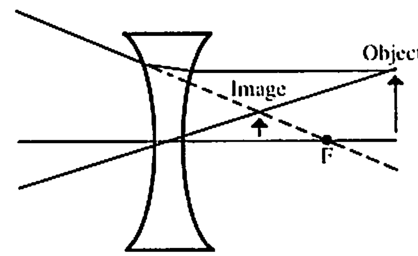
Practical applications:

- eyeglasses

Quantitative requirements include applications of the relationships

$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$ and $\frac{S_o}{S_i} = \frac{d_o}{d_i}$

Diverging lenses are used to correct nearsightedness.



C. Defects in Lenses

1. Chromatic aberration

Chromatic aberration results when all the colors of light do not come to a focus at the same point.

Violet light focuses closer to the lens than red light.

When infrared film is used, the focal length of the camera lens must be adjusted.

Chromatic aberration is caused by dispersion. It can be corrected by using a diverging lens with the converging lens of a different material to eliminate the dispersion.

2. Spherical aberration

Spherical aberration results when all the rays do not come to focus at the principal focus.

Spherical aberration results from rays passing through the edges of the lens.

Spherical aberration can be corrected by using a diaphragm to cover the edges of the lens.

Unit Ten

SOLID STATE PHYSICS

Content Outline/ Understandings/ Concepts

I. CONDUCTION IN SOLIDS

A solid may be classified as a conductor, an insulator, or a semiconductor based on its ability to carry an electric current.

Computers that used to fill a room can now be held in a person's lap.

A. Conduction

Conduction is measured by conductivity, the reciprocal of resistivity.

Resistivity is a quantitative indication of the resistance of a material at a specific temperature. For example, at room temperature the resistivity of copper, a conductor, is ~ 10^{-8} Ω·cm; the resistivity of glass, an insulator, is ~ 10^{12} Ω·cm. The higher the resistivity, the greater the resistance.

1. Conductors

Conductors are typically metallic solids such as aluminum and copper.

Practical applications:
- electric wire

2. Semiconductors

Semiconductors are typically metalloids such as germanium and silicon.

Practical applications:
- computer
- calculator
- pacemaker

3. Insulators

Insulators are typically nonmetallic solids such as glass and rubber.

Practical applications:
- insulation on electric wires

B. Theories of solid conduction

1. Electron-sea Model

The Electron-sea Model relates conduction to the number of valence electrons which can be dislodged and moved through the crystal freely.

This model is limited in its ability to account for the conductive properties of semiconductors.

Valence electrons are those occupying the outermost principal energy level of an atom.

Students may be familiar with the Electron-sea Model if they have studied chemistry.

2. Band Model

The Band Model is more successful in explaining conduction in solids.

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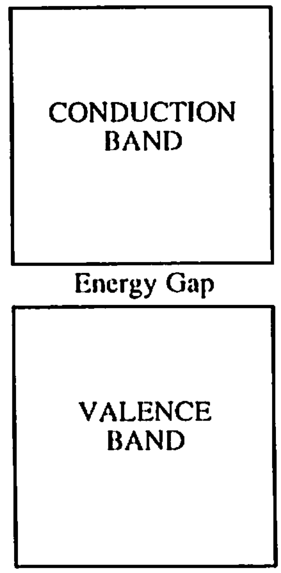
Close-lying electronic levels form a series of energy bands which are separated by an energy gap. The valence band contains the electrons in the outermost level. The conduction band is occupied by those electrons that serve as current carriers.

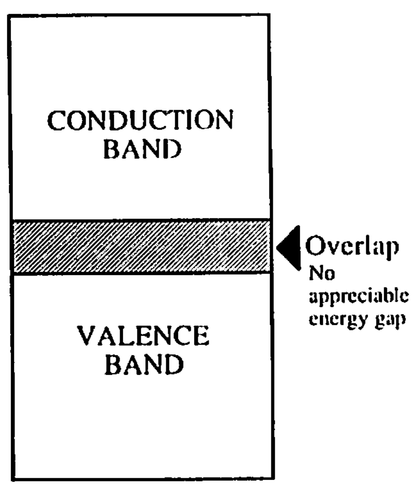
A solid is classified as a conductor, insulator, or semiconductor depending on the size of the energy gap and the number of electrons that can occupy the conduction band.



If the class has studied chemistry, explain how the atomic energy levels relate to electronic bands.

a. Solids as conductors

Solids classified as conductors have conduction bands that overlap the valence bands. This results in the ability of large numbers of electrons to move freely throughout the solid.



Metals with small numbers of valence electrons (e.g., lithium) are able to have their valence bands serve as conduction bands.

1) Effect of temperature

Conductivity decreases with increasing temperature due to the increase in the number of collisions between conduction electrons and the atom kernels which are part of the crystal lattice. The collisions result in the conversion of electron kinetic energy to heat.

Unifying themes: Conservation of energy

Atom kernels are positive ions which consist of the atom devoid of the conduction electrons.

b. Solids as semiconductors

Solids classified as semiconductors are characterized by small energy gaps between valence and conduction bands.

Silicon and germanium have a diamond-like crystalline structure. For example, the four valence electrons of silicon atoms form covalent bonds with adjacent

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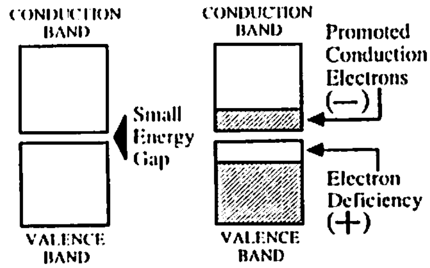


atoms and there are no free electrons, unless they have been freed by the addition of excitation energy (as heat or light, for example).

Show a diagram of a three-dimensional tetrahedral structure of the crystalline structure for silicon.

1) Effect of temperature

At low temperatures, semiconductors behave as insulators. At higher temperatures, however, electrons with increased kinetic energy can make the transition from the valence band to the conduction band. In this way the band model explains why the conductivity of semiconductors increases with increasing temperature.

Semiconductors which have their conductivity increased by increasing the temperature are termed intrinsic semiconductors.

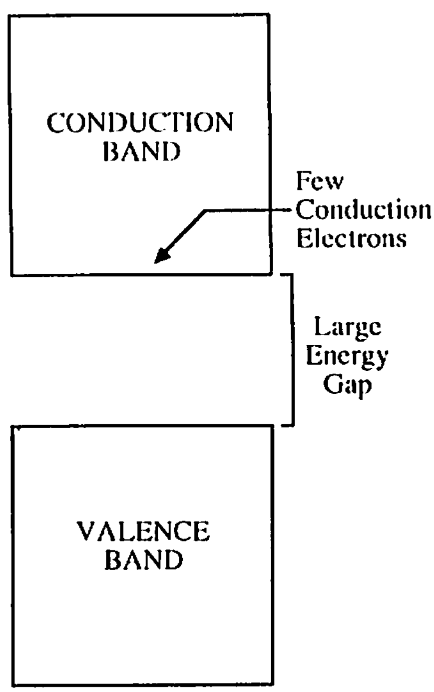
2) Charge carriers

The promotion of electrons into the conduction band leaves behind an electron deficiency in the valence band. Both the conduction electrons (negative) and the deficiency (positive) can serve as charge carriers in the semiconductors.

These electron deficiences are called holes. The holes act like + electrons.

c. Solids as insulators

Solids classified as insulators have their valence and conduction bands separated by a large energy gap which serves as an effective barrier to electrical conduction.



Valence bands do not serve as conduction bands in insulators (as with certain metals) because these bands are usually filled, or nearly so. This situation provides for little electron mobility within the valence band.

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C. Extrinsic Semiconductors

1. Doping

Doping is a process in which very small amounts of another element are added to a semiconducting material such as silicon or germanium.

The doping process either produces an excess of free electrons or a deficiency of electrons; i.e., an excess of holes.

The doping process may involve melting the semiconductor material and the doping element added. For example, a crystal grown from the melt will have the doping element distributed evenly throughout.

A more common doping technique is to deposit the impurity on the surface of the crystal and then heat it so that the impurity diffuses inward.

The ratio of doping atoms to semiconductor atoms is quite small: usually on the order of $1:10^8$. A rough analogy of this ratio would be a few red ping pong balls in a standard room filled with white ones.

2. N-type Semiconductors

A semiconductor with an excess of free electrons is called an N-type semiconductor.

Measure the current through an N-type semiconductor in a forward and reverse direction. Compare the values for each case.

a. Donor materials

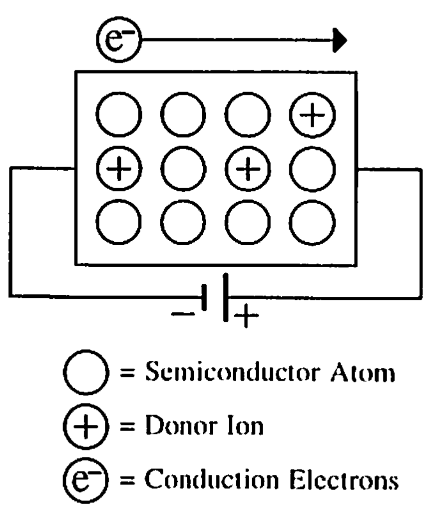
Materials such as antimony or arsenic are termed "donor" materials because they provide extra electrons to the semiconductor.

When the donor material provides its electron, the electron is promoted close to the conduction band leaving a positive ion behind in the crystal lattice.

b. Conduction in N-type semiconductors

If a potential difference is applied across an N-type semiconductor, the conduction electrons will move in the direction of the higher (positive) potential.

The majority charge carriers in an N-type semiconductor are electrons. The holes are the minority charge carriers.



3. P-type semiconductors

A semiconductor with a deficiency of electrons is called a P-type semiconductor. The absence of an electron is called a "hole." A "hole" may be considered to behave in many respects as if it were

Measure the current through a P-type semiconductor in a forward and reverse direction. Compare the values for each case.

Use a piece of glass tubing and slowly bubble air into a container of water. Note that the observation of the freely rising bubble is equivalent to an observation of the water falling. This is analogous to the motion of electron hole currents.

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a positively charged electron.

If a doping agent from Group 13 (containing only three valence electrons) such as indium, gallium, or aluminum were used, there would be a deficiency of one electron for each atom of the doping material, producing a P-type semiconductor.

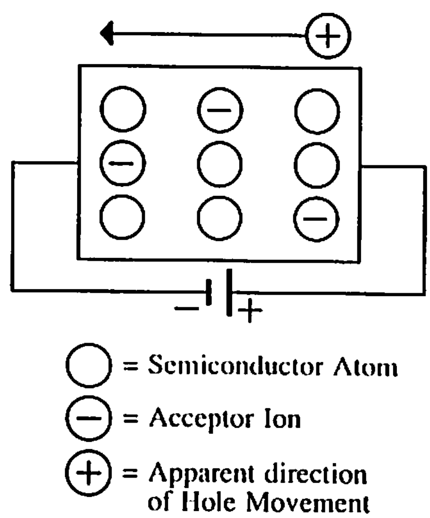
a. Acceptor materials

Materials such as indium, gallium, or aluminum which provide "holes" to semiconductors are termed "acceptor" materials because they create the hole by accepting a bound valence electron.

When the acceptor material receives the bound electron, a negative ion is formed in the crystal lattice.

b. Conduction in P-type semiconductors

If a potential difference is applied across a P-type semiconductor, bound electrons will migrate into the holes and each hole will appear to move in the direction of the lower (negative) potential.



Electron currents and hole currents behave similarly as far as external circuits are concerned. But the two modes of conduction are, in fact, quite distinct, and are basic to diode and transistor theory.

The majority charge carriers in a P-type semiconductor are holes. The electrons are the minority charge carriers.

Practical applications:

- thermistors

II. SEMICONDUCTOR DEVICES

A. The (junction) diode

The diode is the simplest and most fundamental semiconductor device used in electronics. It acts as a one-way valve letting charge flow through it in one direction, while blocking charge flow in the other.

Recognize the symbol for the diode.

Practical applications:

- solar cell
- LED display (calculator, digital clock)

The presence of an "arrow" in any semiconductor device always points from "P" to "N".

1. The P-N junction

A diode is made by joining a P-type semiconductor with an N-type semiconductor. The interface

AC may enter a diode, but only DC will leave the diode.

P-N junctions may be produced by changing the impurities as a single crystal is grown, or they may be produced by

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between the two types of semiconductors is called a P-N Junction.

When the P-type and N-type semiconductors are joined to produce a P-N junction in the very narrow region between the N-type and P-type materials, free electrons from the N-type material drift into the P-type material and fall into the holes there, so that in the junction region, there are fewer free charges of either sign.

As a result of the electron-hole combinations, an excess of positive charge remains in the N-type material, and an excess of negative charge remains in the P-type material. These excess charged particles establish an electric field barrier (potential barrier) which prohibits further migration across the P-N junction.

2. Diode conduction

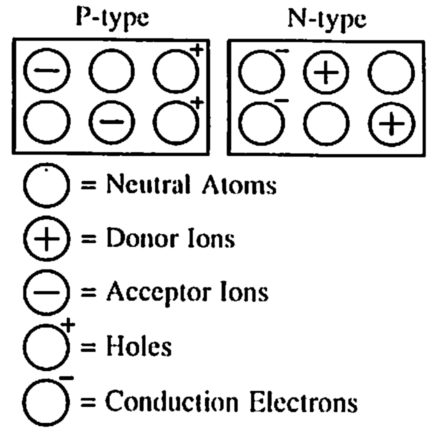
When a potential difference is placed across a diode, the electric field barrier across the P-N junction may be either reinforced or diminished depending on the polarity of the potential difference. This phenomenon is known as "biasing."

a. Forward biasing

A diode is forward biased when the anode of the diode is connected to the positive terminal and the cathode is connected to the negative terminal of the source. This connection establishes an electric field which overcomes the barrier field and supports the presence of current. Current does not flow until the forward bias exceeds the barrier potential.

b. Reverse biasing

A diode is reverse biased when the anode of the diode is con-



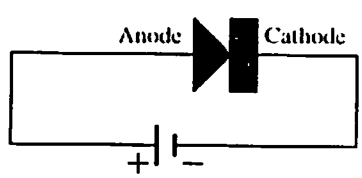
Practical applications:

- rectification
- laser diode
- circuit protection

Requirements include circuit diagrams representing forward and reverse biased diodes and the affects of AC.

Practical applications:

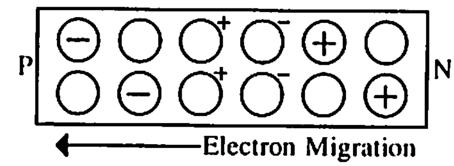
- pocket calculator
- digital clock



Practical applications:

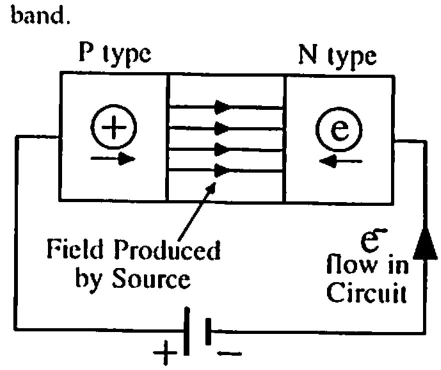
- burglar alarm

diffusion. For instance, a P-type impurity may be deposited on the surface of an N-type material and when the material is heated, the P-type impurities can diffuse in, forming a junction.



Explain the significance of diode characteristics and go over, in some detail, some of the applications of diodes.

In light emitting diodes (LED's), visible light is emitted when an electron returns from the conduction band to the valence band.



Photodiodes use light to promote electrons into the conduction band. Hence,

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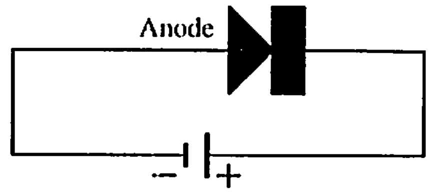
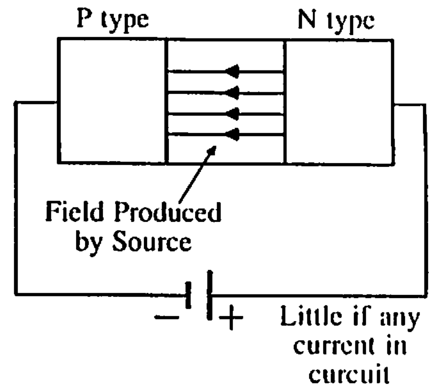
nected to the negative terminal of the source. This connection reinforces the electric field barrier across the P-N junction and effectively prohibits the flow of charge.

- automatic door opener
- Zener diode



they can detect when a beam of light has been broken.

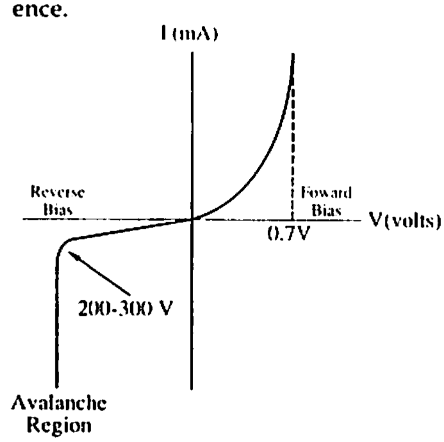


c. Current characteristics

When forward biased, the diode does not obey Ohm's Law.

When reverse biased, hardly any current is present until a massive potential difference (200-300 V) causes the diode to "avalanche" (break down). The more heavily doped, the lower the voltage for breakdown.

Requirements include interpretation of graphs of current vs. potential difference.



Avalanche can occur in a Zener diode with as little as 3.4V.

For example, diodes can serve as half-wave rectifiers for AC. Rectification occurs because the diode is alternately forward and reverse biased due to the presence of an alternating potential difference.

PNP & NPN Transisters

B. Transistors

A transistor consists of two junction diodes sharing a common semiconductor material.

1. PNP transistor

   If an N-type material is shared, the transistor is termed PNP.

2. NPN transistor

   If a P-type material is shared, the transistor is termed NPN.

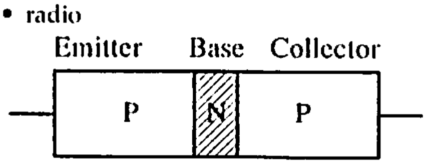
3. Parts of a transistor

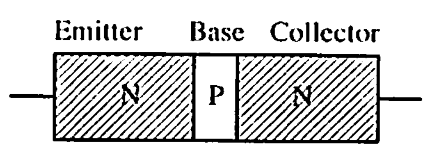
   a. Emitter

   The emitter serves as the primary source of charge carriers (electrons in NPN transistors and holes in PNP transistors).

Practical application:

- radio





The term "transistor" is a contraction of the words transfer and resistor.

Junction transistors are similar to triodes. They are also called bipolar transistors.

The emitter is more heavily doped than either the collector or the base.

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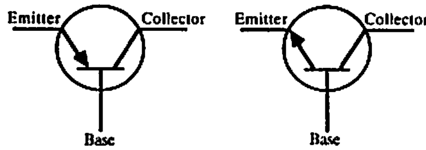
b. Base

The base is a thin layer of semiconductor material common to both diodes.

c. Collector

The collector receives the charge carriers from the base.

Symbols for transistors:



Transister Symbols

Base layers are typically less than 100 nm thick.

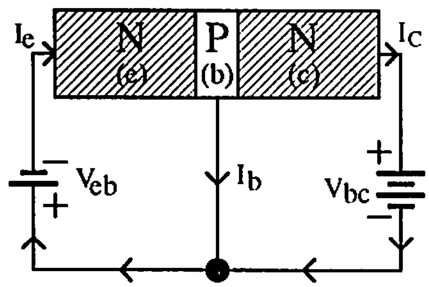
The resistance of the base-collector junction is on the order of 10^5 ohms; the resistance of the emitter-base junction is on the order of 10^2 ohms. These numbers are for a common base circuit. If the current is reversed, the resistance values will reverse also.

4. Transistor operation

For an NPN transistor the emitter-base combination is forward biased; the collector base combination is reverse biased.

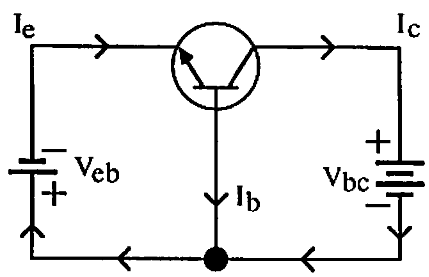
Approximately 98% of the electrons pass from the emitter through the base to the collector. This is a result of the scarcity of holes in the base due to its extreme thinness. The end result is that the collector current is only slightly smaller than the emitter current.

The small base current is a result of electron-hole combinations within the base. The withdrawal of electrons creates new holes in the base.



e = Emitter
b = Base
c = Collector
(←) Indicates Electron Flow

V = Potential Difference
I = Current



Equivalent Diagram with Symbols

Operation of a PNP transistor is essentially the same as that of an NPN transistor with polarities reversed and hole currents replacing electron flow. Illustrate NPN and PNP transistor operation using suitable diagrams.

5. Amplification properties of transistors

a. Collector current

Small changes in the emitter-base current bring about large changes in the collector current.

b. Transistorized circuits

In transistorized circuits, a low power signal is input (usually as an alternating current) and

The transistor acts as a valve in which a small amount of power from the emitter battery controls a large amount of power from the collector battery.

Transistors are used in microphone-speaker circuits to provide sufficient output power.

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the output is an amplified reproduction of the signal.		
c. Integrated circuits		
An integrated circuit (IC) consists of a small semi-conductor "chip" (usually silicon) which contains many electronic components in one package.	Practical applications: • microprocessor • computer logic chip	Discuss the difference between analog and digital signals, and the many uses to which IC's have been put.
IC's have revolutionized the electronics industry because of the capacity of an IC to combine versatility and miniaturization. IC's have increased the use of digital circuitry in our lives.		

Unit Eleven

NUCLEAR ENERGY

Content Outline/ Understandings/ Concepts | **Discrepancies/ Practical Applications/ Activities** | **Supplementary Information**

I. THE NUCLEUS

The nucleus is the core of the atom and contains most of the mass of the atom.

A. Nucleons

The particles inside the nucleus, protons and neutrons, are called nucleons.

B. Atomic number

The atomic number is the number of protons in the nucleus. The symbol for the atomic number is Z.

Elements differ from each other in atomic number.

Examples of nuclei are given to illustrate concepts. Memorization of these examples is not required.

A neutral atom has Z electrons as well.

C. Mass number

The mass number is the total number of protons and neutrons in the nucleus. The symbol for the mass number is A.

Example: $^{14}_{6}C$ is the symbol for carbon with a mass number of 14 and an atomic number of 6.

D. Nuclear force

Nuclear force is the force which holds the nucleons together. It is a strong short range force.

Nuclear forces operate when the distance between nucleons is less than 10^{-15}m.

Nuclear forces are the strongest forces known; they exceed the electrostatic force by about two orders of magnitude.

Nuclear force is a result of the strong interaction.

E. Atomic mass unit

The atomic mass unit (u) is defined as 1/12 the mass of an atom of carbon-12.

$1u = 1.66 \times 10^{-27}kg$

$mass_{carbon} = 12.0000u$

$mass_{proton} = 1.00\,73\ u$

$mass_{neutron} = 1.00\,87\ u$

$mass_{electron} = 0.0005\ u$

*F. Mass-energy relationship

Mass is equivalent to energy. They are the same thing, although we usually use different units (kg or J) for them. In nuclear physics, however, mass is usually given in energy units (MeV, etc.).

Unifying theme: Conservation of energy

In pair production, a gamma ray is annihilated forming an electron and positron. If these two particles collide, two gamma rays are emitted. Mass-energy is conserved in both of these reactions.

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Einstein's mass-energy equation states that the energy equivalent of mass is proportional to the mass and the speed of light squared. $E = mc^2$		Chemical reactions also change the masses of the reactants, but the released energies are so small that the rest mass changes are negligible. The equation $E = mc^2$ may be used to calculate the energy equivalent of the atomic mass unit (u): $E = 1.66 \times 10^{-27} kg (3.00 \times 10^8 m/s)^2$ $E = 1.49 \times 10^{-10} J$ $E = 1.49 \times 10^{-10} J/(1.60 \times 10^{-19} J/eV)$ $E = 931 MeV$ = mass of 1 u
*** G. Nuclear mass and binding energy** The mass of the nucleus is less than the total mass its nucleons would have if they were separated. The mass defect is the difference in mass between the total mass of the separated nucleons and the mass of the nucleus. The mass defect is equivalent to the energy released when the nucleons are bound.	Unifying theme: Conservation of energy.	$m_{proton} = 1.67 \times 10^{-27} kg = 1.0078 u$ $m_{neutron} = 1.67 \times 10^{-27} kg = 1.0087 u$
Binding energy is the energy that must be supplied to the nucleus in order to separate it into its nucleons. The binding energy is the energy equivalent of the mass defect.	Quantitative requirements include calculating the mass defect and binding energy for a nucleus.	The binding energy is the energy released when the nucleons are "put together" to form a nucleus. Binding energies are usually compared in terms of binding energy per nucleon. The highest binding energy per nucleon occurs for a mass number of about 60. For elements above carbon, the binding energy per nucleon is about 8 MeV.
H. Isotopes Different isotopes of the same element have nuclei with the same atomic number but a different number of neutrons.	Example: $^{238}_{92}U$ and $^{235}_{92}U$ are both isotopes of uranium.	Most of the naturally occurring radioactive isotopes have atomic numbers greater than 81.
I. Nuclides A nuclide is a single nuclear species. Every nucleus of a given nuclide has the same number of protons and neutrons, or mass number. Different nuclides with the same atomic number are isotopes of the same element.		Other radioactive nuclides which do not occur in nature may be produced in the laboratory or in nuclear devices such as bombs and nuclear reactors.
J. Methods of learning about the atom 1. Particle accelerators A particle accelerator is a device used to project charged particles at high speed into matter. Electric	*Some particles can be accelerated to 10^8 m/s.*	Charged projectiles include electrons, protons, alpha particles, and deuterons.

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and magnetic fields are used to provide the forces to accelerate and control these charged particles at speeds approaching the speed of light. When these charged particles strike the nucleus of an atom, they alter its stability and new particles may be produced.	Practical applications: • Van de Graaff generator • cyclotron • betatron • synchrotron • linear accelerator	Discuss the construction of larger and larger accelerators to provide charges with higher and higher energies to detect smaller and smaller particles.
2. Detection devices Various devices used to detect subatomic particles are the Geiger counter, ionization chamber, bubble chamber, cloud chamber, spark chamber, scintillation counter, and photographic film.		Many of the methods of detecting high energy particles depend on the ionization process. When a charged particle moves through matter, it removes electrons from atoms in its path leaving a trail of positive and negative ions.
3. Subatomic particles In addition to the proton, neutron and electron, other subatomic particles are also observed to exist.	Practical applications: • neutrino • positron • negative proton	Elementary particles have antiparticles that have the same mass but opposite charges. The positron is the antiparticle of the electron, and the negative proton is the antiparticle of the proton. Other properties are also involved, so that, for instance, the neutron has an antineutron.
It is now known that some nuclear particles (protons, neutrons, and hyperons), called baryons, as well as the intermediate mass mesons, are composed of constituent particles called quarks.		No particle with a charge smaller than $\pm e$ has been isolated. However, quarks have charges of $\pm e/3$ and $\pm 2e/3$. Quarks cannot be isolated from the particles that they form.

II. NUCLEAR REACTIONS

A. Natural radioactivity

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Natural radioactivity is the spontaneous disintegration of the nuclei of atoms which occur in nature.	*One element can become another, naturally.* Practical applications: • medical diagnosis • medical treatment • power plant	Isotopes with very short half-lives and which will be quickly eliminated from the body are used for diagnostic injections. Technetium-99, not a naturally occurring element, is used for locating brain tumors. Iodine-131 is used for diagnosing thyroid disorders.
Some nuclei, generally of high atomic number, are naturally radioactive.	Memorization of nuclear equations is not required. Recognize natural radioactive decay when illustrated by a nuclear equation.	Radium and cobalt-60 (which is not found in nature) are used in cancer therapy.
In all nuclear reactions, the sum of the charges and the sum of the mass numbers on both sides of the equation are equal.	Unifying themes: Conservation of energy, Conservation of charge.	Radiation kills bacteria, yeasts, molds, and insect eggs in foods, permitting the food to be stored without spoilage for a much longer time than untreated food.
1. Alpha decay Alpha decay is the spontaneous emission of an alpha particle from a nucleus.	Example: $^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ^{4}_{2}He$	The fact that the mass numbers are the same on both sides is not an example of

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An alpha particle is the nucleus of a helium atom. It has a mass number of 4 and a charge of +2. The emission of an alpha particle decreases the mass number by four and the atomic number by 2.	Practical application: • radon gas in homes	mass-energy conservation, but conservation of baryon number. Discuss the environmental and health concerns associated with radon gas in homes.
2. Beta decay (negative) In natural radioactivity, beta decay is the spontaneous emission of a negative electron from a nucleus. The emission of a negative beta particle increases the atomic number by one but does not change the mass number.	Example: $^{234}_{90}Th \rightarrow ^{234}_{91}Pa + ^{0}_{-1}e$	Beta decay can also emit a positron (antielectron), $^{0}_{+1}e$ An antineutrino, $\bar{\nu}$, is also emitted during negative beta decay. Beta decay can occur because of the weak interaction.
3. Gamma radiation Gamma radiation consists of high energy photons originating in nuclear reactions. The emission of gamma radiation does not change the atomic number or mass number. Gamma radiation is emitted when a nucleus in an excited state changes to a more stable state.		Gamma radiation is evidence of nuclear energy levels. Emission of an alpha or a beta particle may leave the nucleus in an excited state which may emit a gamma ray, resulting in a lower energy level for the nucleus.
***B. Half-life** The half-life of a radioactive element is the time required for one-half of the nuclei of a sample to disintegrate. Each radioactive nuclide has a specific half-life. $m_f = \frac{m_i}{2^n}$	Practical applications: • carbon-14 dating • dating rocks	The half-life of uranium-238 is 4.5×10^9 years. The half-life of carbon-14 is 5730 years. The ratio of uranium-238 to lead-206 in a mineral can be used to determine the age of the mineral. The ratio of carbon-14 to other carbon isotopes in a sample can be compared to that in the atmosphere, permitting the age of the sample to be estimated.
C. Conservation of mass-energy During the process of radioactive decay, mass-energy is conserved.	Unifying theme: Conservation of energy	
D. Artificial transmutation *Transmutation* is a change from one nuclide to another because of a gain or loss of protons and/or neutrons by the nucleus. Radioactivity is an example of natural transmutation. Artificial transmutation may be produced by bombardment of nuclei with alpha particles, protons, neutrons, or other particles. Artificial	Recognize artificial transmutation when illustrated by a nuclear equation. Practical applications: • medical diagnosis • medical treatment Example: $^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$	This was confirmed experimentally with accelerated protons by Cockcroft and Walton in 1932: $^{7}_{3}Li + ^{1}_{1}H \rightarrow ^{8}_{4}Be \rightarrow ^{4}_{2}He + ^{4}_{2}He$ In 1919, Rutherford bombarded nitrogen with alpha particles from a radioactive source and produced oxygen. This was the first artificial transmutation. Accelerators are used to give charged

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transmutation may also be produced when an incident high energy photon ejects a proton or a neutron or causes the nucleus to become unstable and disintegrate. Artificial transmutation may result in the production of a nuclide that is radioactive.	Example: $^{27}_{13}Al + ^{4}_{2}He \rightarrow ^{30}_{15}P + ^{1}_{0}n$ The radioactive phosphorous then decays to a stable isotope of silicon. $^{30}_{15}P \rightarrow ^{30}_{14}Si + ^{0}_{+1}e$	particles sufficient kinetic energy to overcome the electrostatic forces and penetrate the nucleus. The first induced radioactivity occurred in 1934 when the Joliet-Curies bombarded aluminum with alpha particles to produce a radioactive isotope of phosphorus.
1. Positron emission Beta decay in artificial transmutation includes the emission of positive electrons (positrons) as well as negative electrons from the nucleus.		
The emission of a positive beta particle decreases the atomic number by one but does not change the mass number.	Example: $^{64}_{29}Cu \rightarrow ^{64}_{28}Ni + ^{0}_{+1}e$	A neutrino, ν, is also emitted during positive beta decay. When the neutron to proton ratio of a nuclide is too low for stability, a proton may be converted to a neutron through either the process of positive beta decay or that of electron capture.
The emission of a negative beta particle increases the atomic number by one.	Example: $^{24}_{11}Na \rightarrow ^{24}_{12}Mg + ^{0}_{-1}e$	
2. Electron capture (K-capture) Electron capture occurs when the nucleus absorbs an orbital electron. Electron capture decreases the atomic number by one, but does not change the mass number.	Example: $^{40}_{19}K + ^{0}_{-1}e \rightarrow ^{40}_{18}Ar$	The electron captured is from the very innermost shells.
3. The neutron Neutrons were first discovered by bombarding beryllium with alpha particles.	Example: $^{9}_{4}Be + ^{4}_{2}He \rightarrow ^{12}_{6}C + ^{1}_{0}n$ This is an example of artificial transmutation.	The neutron was identified in 1932 when Chadwick bombarded beryllium with alpha particles.
In nuclear reactions, neutrons are often used as bombarding particles because they are uncharged and are not repelled by nuclei. When neutrons come very close to a nucleus, the neutrons are attracted to the nucleus.		It is not necessary to give neutrons high kinetic energies in order for them to participate in nuclear reactions. In some cases it is advantageous to slow down the neutrons so they spend more time near the nucleus.
F. ***Nuclear fission*** Fission is the splitting of the nucleus of an atom. Fission occurs primarily as the result of the nucleus capturing a neutron. Fission produces fragments and energy and releases two or more neutrons. The liberation of energy is the result of the dispersion of part of the original concentrated mass-energy.	Practical applications: • nuclear power plant • atomic bomb Recognize a fission reaction when illustrated by a nuclear equation. Example: $^{235}_{92}U + ^{1}_{0}n \rightarrow F_1 + F_2 + \zeta n + Q$ Where F_1 and F_2 are fission fragments, ζ	Fission is the process used by conventional nuclear power plants and some nuclear weapons. The energy is released as thermal energy of the various fragments and radiation. A discussion of nuclear weapons may be of interest. Some nuclei can undergo fission as the

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Only certain elements of high atomic number can be fissioned.	represents the average number of neutrons emitted per fission, and Q represents the energy.	result of excitation by a gamma ray of sufficient energy. The energy released per nucleon in the fission of a heavy element is the difference between the average binding energy per nucleon of the original element and the average binding energy per nucleon of the fission fragments formed.
1. Nuclear Fuels A nuclear fuel is a fissionable nuclide used to produce energy on a commercial scale. Nuclear fuel is formed into pellets stacked in rods. The fuel rods are then placed in the core of the reactor.	*A uranium fuel pellet ($3cm^3$) has as much energy as a ton of coal.* Practical applications: • uranium-235 • plutonium-239	Natural uranium (99.3% uranium-238 and 0.7% uranium-235) and enriched uranium (3 to 4 percent enrichment with uranium-235) are commonly used as fuels in heavy water and light water reactors, respectively. Uranium-233, produced from neutron capture by thorium-232, and plutonium-239, produced from neutron capture by uranium-238, are obtained as fuels in breeder reactors. Breeder reactors produce more fuel than is consumed.
2. Thermal neutrons Thermal neutrons are neutrons with kinetic energies nearly equal to those of the molecules of a substance at ordinary temperatures, about $^1/_{25}$ eV. Thermal neutrons with smaller kinetic energies are more likely to undergo absorption by a nucleus and are therefore more likely to cause fission reactions.		Fission of uranium-235 is induced by thermal neutrons.
3. Moderators For efficient nuclear fission, it is necessary to slow down the speed of the neutrons. Moderators are materials that have the ability to slow down neutrons quickly with little tendency to absorb them.	Unifying theme: Conservation of energy, Conservation of momentum	A macroscopic analogy of this collision process consists of two suspended balls of equal mass. When a moving ball strikes a stationary ball, the moving ball stops and the other ball moves off with the same velocity as the original. This can be verified by the laws of momentum and energy conservation.
Particles of low mass, comparable to that of the neutron, such as hydrogen and its isotope deuterium (D) have been found to be effective as moderators. The neutrons are slowed down most effectively by a head-on collision with a particle of similar mass.	Practical applications: • water • heavy water (D_2O) • beryllium • graphite	Graphite is relatively low in cost, easily machined, and is sufficiently strong as a structural material. It is, however, fragile when struck, can interact with oxygen in the air, and suffers radiation damage at temperatures lower than 250°C. Normal light water cannot be used in a reactor with natural uranium fuel, because the hydrogen would absorb too many neutrons. Heavy water has to be used in such reactors because deuterium

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		does not absorb as many neutrons. Light water can be used in uranium-235 enriched reactors.
4. Chain reaction A chain reaction is a self-sustaining reaction which, once started, steadily provides the energy and neutrons necessary to continue the reaction. Some of the excess neutrons released in each fission are absorbed by other uranium-235 atoms, causing them to undergo fission. A critical mass is the minimum amount of fissionable material necessary for a chain reaction to occur.		In a nuclear reactor, the chain reaction can be controlled. In a nuclear bomb, the chain reaction is not controlled.
5. Control rods The fission process in a reactor can be controlled by adjusting the number of neutrons available. A control rod is a device used to absorb neutrons in a nuclear reactor.	Practical applications: • boron • cadmium	If the control rods are removed, neutrons will not be absorbed, and the reaction accelerates. If the control rods are inserted too far, there will be too few neutrons, and the chain reaction is no longer self-sustaining.
6. Coolants Coolants are used to keep the temperatures generated by fission at reasonable levels within the reactor and to carry heat to heat exchangers and turbines.	Practical applications: • water • heavy water	In some reactors the coolant also serves as the moderator. Water, heavy water, air, helium, carbon dioxide, molten sodium, and molten lithium are examples of coolants. Discuss the tremendous quantities of heat released to the atmosphere by the cooling towers of nuclear generating stations.
7. Shielding The internal shield protects the walls of the reactor from radiation damage. The external shield serves to protect the personnel from radiation.		Steel lining is used for internal shielding, and high density concrete is used for external shielding.
8. Radioactive wastes Fission products from nuclear reactors are intensely radioactive and cannot be discarded. They must be stored for a long time or disposed of in special ways. Solid and liquid wastes are encased in special containers for permanent storage underground or in isolated areas.	Practical applications: • strontium-90 • cesium-137	The process of vitrification, solidifying high-level wastes to prevent dissolving and corrosion, should be discussed. The atoms in many parts of the reactor

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Low-level radioactive wastes may be diluted and released directly into the environment.

that are exposed to the radiation will be subject to artificial transmutation, generating "activation products," many of which will also be dangerously radioactive. At decommissioning, the entire structure may have to be treated as radioactive waste.

Gaseous radioactive wastes are stored for decay to safe levels and then dispersed into the air.

Practical applications:
- radon-222
- krypton-85
- nitrogen-16

Discuss the environmental impact of long-term storage of radioactive wastes.

a. Production of plutonium:

When uranium-238 absorbs a neutron, the resulting reaction produces plutonium.

Uranium-238 does not fission with thermal neutrons.

Plutonium may be treated as waste or be used as a fuel since it undergoes fission.

Example:

$^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{92}U \rightarrow ^{239}_{93}Np + ^{0}_{-1}e$

$^{239}_{93}Np \rightarrow ^{239}_{94}Pu + ^{0}_{-1}e$

Fuels used in conventional nuclear reactors contain more uranium-238 than uranium-235.

Due to limited supplies of uranium-235, plutonium-239 was used in the first test-firing of a nuclear weapon in New Mexico in 1945.

G. **Fusion reaction**

Fusion is the process of combining two light nuclei to form a heavier nucleus.

When two light nuclei fuse into a heavier nucleus, they form a more stable nucleus having a greater binding energy per nucleon. The mass of the heavier nucleus formed is less than the sum of the masses of the lighter nuclei; the difference in mass is converted into emitted photons.

The energy released per nucleon in a fusion reaction is much greater than the energy released per nucleon in a fission reaction.

Electricity can be made from sea water.

Unifying theme: Conservation of energy.

Recognize a fusion reaction when illustrated by a nuclear equation.

Example:

$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{4}_{2}He + Q$

Practical applications:
- solar energy
- hydrogen bomb
- future energy plants

For fusion reactions, the fuel must be in plasma form, requiring extremely high temperature and pressure.

The sun's energy is produced in a series of fusion reactions which result in the conversion of the Sun's hydrogen into helium. Extremely high temperatures and pressures, such as those deep in the Sun's interior are needed for these reactions. The nuclear reaction of a hydrogen bomb utilizes fission as a trigger to generate the temperatures and pressures needed for fusion.

1. Fuels

   Deuterium ($^{2}_{1}H$) and tritium ($^{3}_{1}H$) may be used as fuels.

2. High energy requirement

   Since each nucleus carries a positive charge, nuclei repel one another electrostatically. Consequently, for nuclei to interact, they must have enough kinetic energy to overcome repulsion.

Examples:

$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{1}H + ^{1}_{1}H + Q$

where Q = 4.0 MeV

$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + Q$

where Q = 17.6 MeV

Heavy water (deuterium oxide) is obtained by concentrating the trace quantities present in water. Tritium is made by the nuclear reaction:

$^{6}_{3}Li + ^{1}_{0}n \rightarrow ^{3}_{1}H + ^{4}_{2}He$

Since the magnitude of repulsion increases with charge, only the nuclei of lowest possible charge can be used. Fusion with ordinary hydrogen, however,

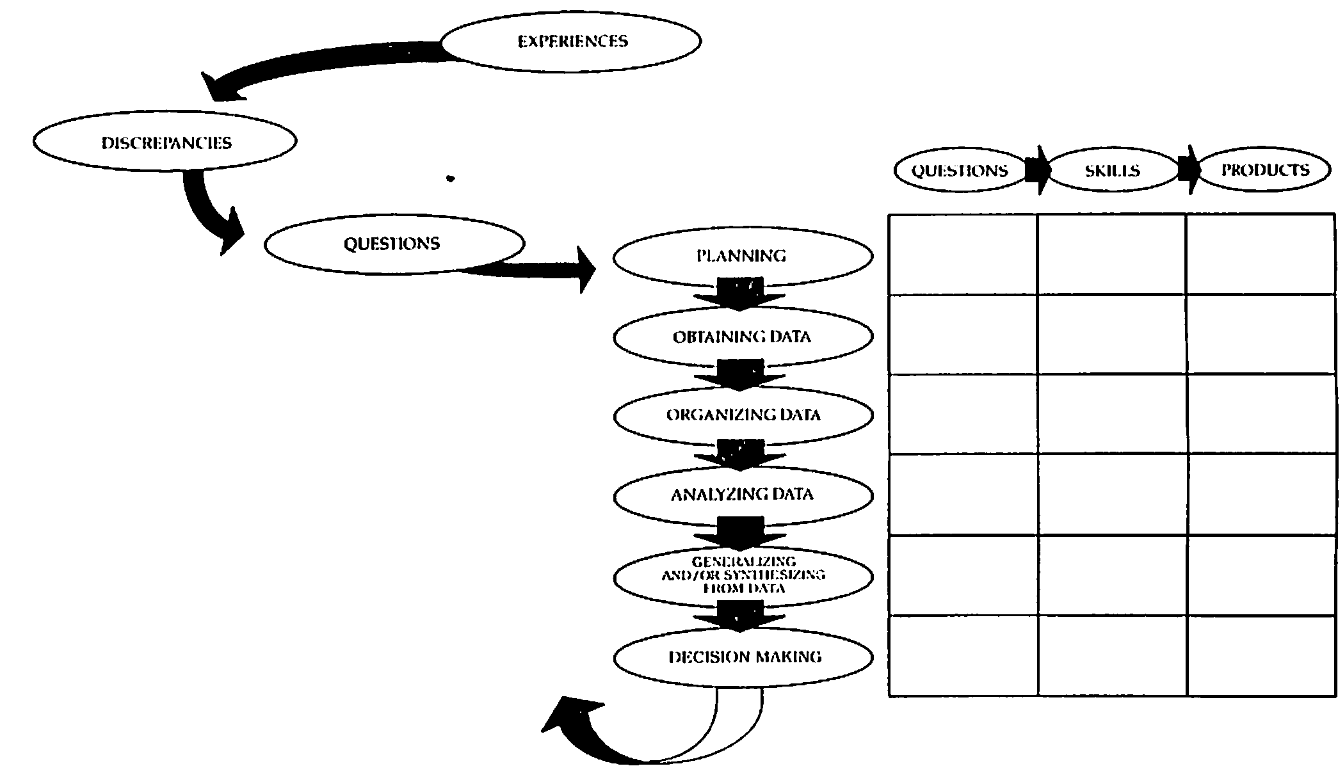
Content Outline/ Understandings/ Concepts	Discrepancies/ Practical Applications/ Activities	Supplementary Information
The thermonuclear approach, through the use of very high temperatures, appears to be promising for controlled fusion.		has a very low reaction probability. Fusion reactions involving deuterium, or deuterium and tritium, are useful sources for the release of energy. Of these, the most likely reaction is between deuterium and tritium. Technical problems with nuclear fusion, such as the requirement of extremely high temperatures and their containment, continue to challenge nuclear scientists and engineers.

Appendix A

EXAMPLES OF QUESTIONS, SKILLS, AND PRODUCTS IN A PROBLEM-SOLVING MODEL

STEPS / FOCUS QUESTIONS	SKILLS	PRODUCTS
Planning 1. What is the problem? 2. What background information do I already have? • What do I already know about . . .? 3. What new information do I need? 4. What procedure or experimental design do I need to follow? • How can I find what I need to know about . . .? 5. How will I know when I have solved the problem?	• Recognizing a problem • Communicating information • Creating models • Formulating hypotheses • Designing experimental procedures	1. A statement of the problem 2. List of facts (background information) 3. List of questions (related to later steps i the process) 4. An experimental design 5. Sketch or description of the expected (predicted) final product
Obtaining Data What information is needed? • What are the properties of . . .? • What kinds of . . .? • How long, wide, big . . . is it? • How much does it weigh? • What color is it? • How hot is . . .?	• Selecting instruments • Measuring • Observing • Recording data	• Data charts • Computer printouts • Photographs • Schematics
Organizing Data In what useful way(s) can the information be organized? • Which ones belong to this group? • In what order do these . . . belong? • What categories are there? • How can this be graphed? • What is the result of this . . . calculation?	• Processing data • Creating models	• Calculations or computations • Charts, tables • Diagrams, scale drawings • Graphs • Groups, categories of information • Outline • Sorted objects
Analyzing Data What useful analyses can be made of the organized information? • In what way does . . . compare contrast with . . .? • What seemed to be the effect of . . .? • What seemed to cause . . .? • What must have been the pattern (sequence) of events? • What assumptions were made?	• Interpreting data • Interpolating and extrapolating	• Description of a pattern or sequence • Mathematical relationships • Statements of cause and effect relationships • Independent and dependent variables • Statements of similarities and differenc • Summary

STEPS/FOCUS QUESTIONS	SKILLS	PRODUCTS
Generalizing and/or Synthesizing From Data What can be drawn from the analyses of information? • How can I explain . . .? • How can I show I need to . . .? • What is the principle of . . .? • If this continues, then what is likely to happen? • What might happen if I . . .? • What model shows what we know about . . .? • What new problems does this suggest? • How does . . . apply to . . .?	• Evaluating hypotheses • Creating models • Formulating hypotheses • Generalizing	• A model or simulation • A new hypothesis • A new prediction, problem, theory • Applications to new situations • Statements of principles • Statements which accept or reject hypotheses • Written lab reports
Decision Making 1. What decisions need to be made? 2. What are the alternative choices and the reasons for each? 3. What are the consequences of each alternative? 4. Who will be affected by each possible choice and in what way? 5. What values are directly related to each choice, and how do they relate to it? 6. Which choice is the best choice?	• Acquiring information • Communicating information • Making decisions • Manipulating ideas • Questioning	1. Statement of the decision to be made 2. List of alternative choices, supported by reasons 3. List of consequences of each alternative 4. List of persons directly affected by each choice and the way each is affected 5. List of values related to each choice, supported by statements of how the values relate 6. A personal choice, supported by defendable reasons for the choice



Examples of Problems

1. On the planet "X", the standard units of measurement are not necessarily the same as on Earth. In order to discover the way objects behave along a hard, smooth surface on "X", Earth scientists want to carry out a set of experiments.
   a. What instruments would you take from your school's laboratory? Justify your choice.
   b. Describe how you might use this equipment to measure the acceleration due to gravity on "X".
   c. Local scientists claim the acceleration due to gravity at the testing site is 0.85 whipples/ploobs^2. What questions should you ask in order to confirm this acceleration value as determined with your Earth instruments.
2. Sound generally travels faster through solids than through air. In school, the hallway is very noisy so the teacher closes the door and less noise enters the classroom. Based on what you know about waves, describe what would cause this phenomenon to exist.
3. An automobile manufacturer can design one of two cars: one that is rigid or one that crushes except for the passenger compartment. Based on your knowledge of impulse and momentum, describe the pros and cons of each design.
4. Analogies:
   a. Balance is to mass as ammeter is to:
      1) weight 2) voltage
      3) current 4) circuit
   b. Vector is to scalar as displacement is to:
      1) velocity 2) force
      3) acceleration 4) distance

Appendix B

SKILLS

Skill	Definition	Example – The skill is being demonstrated if the student is:
Applying Mathematics	a) Using mathematical rules or formulas to calculate quantities or determine relationships from basic measurements.	Computing the current in a resistor given the resistance and applied potential by using Ohm's Law.
	b) Estimating answers without performing precise calculations.	Rounding g from 9.8 m/s^2 to 10 m/s^2, and comparing the orders of magnitude of the gravitational force and the electrostatic force between the proton and the electron in a hydrogen atom: 10^{-47} N compared to 10^{-7} N.
	c) Using dimensional analysis to derive units and check for the validity of relationships.	Showing that $s = \frac{1}{2}a(\Delta t)^2$ is dimensionally correct, but $v = 2a$ is not.
Classifying	Arranging or distributing objects, events, or information representing objects or events in classes according to some method or system.	Grouping weight and velocity as vectors and mass and speed as scalars.
Communicating	a) Sharing information, concepts, and attitudes through speaking and writing, using appropriate language.	Submitting clear, concise, and understandable lab reports and describing an experiment at a science fair.
	b) Acquiring information and developing concepts through active reading, listening, and questioning.	Using reference sources such as the *Handbook of Chemistry and Physics* and the reference tables to locate the values for constants needed to solve problems, and recognizing other valuable sources such as local industry, scientific TV shows, and university professors.
Creating Models	Developing analogues of a phenomenon or situation that are easier to understand, calculate, and/or visualize, but which correlate data of the original situation and allow testable predictions of new measurements.	Explaining the Bohr model of the atom or the wave nature of light.
Formulating Hypotheses	Constructing a tentative and testable prediction.	Stating that if a rock is dropped from the same height and at the same time that an identical rock is thrown horizontally, both rocks will hit the ground at the same time.
Generalizing	Drawing conclusions from limited information and applying them in a broader context.	Summarizing experimental results such as: "In the absence of air resistance, objects of different mass fall freely with the same acceleration.

Skill	Definition	Example – The skill is being demonstrated if the student is:
Identifying Variables	Recognizing characteristics or factors that are constant or change under different conditions, and distinguishing between dependent and independent variables.	Noting that at constant temperature for a wire of uniform thickness, the resistance of the wire (dependent variable) is proportional to the wire's length (independent variable).
Inferring	Making a conclusion based on observation, experimentation, and/or reasoning to explain a phenomenon.	Stating that because they have the same acceleration, two blocks of different mass will hit the ground in the same amount of time when dropped from the same height.
Interpreting Data	Analyzing information that has been obtained and organized by determining apparent patterns or relationships among variables.	Noting the direct relationship between the volume and absolute temperature of a gas.
Identifying/Selecting Alternatives	Recognizing available choices and choosing a course of action based on justifiable reasons.	Evaluating various techniques for generating electrical energy.
Manipulating Materials	Handling or treating materials and equipment skillfully, effectively, and safely.	Obtaining a clear image with a converging lens.
Measuring	Making quantitative observations by comparing to a conventional (or nonconventional) standard.	Reading a voltmeter to the proper precision and in the correct units.
Observing	Becoming aware of an object or event by using any of the senses (or extensions of the senses) to identify properties.	Listening to sounds made by different tuning forks to discriminate among their pitches and comparing this to wave forms on an oscilloscope.
Predicting	Making a forecast of future events or expected conditions based on information and/or models.	Stating how far an object will fall in a given length of time.
Recording Data	Collecting facts about objects and events which illustrate a specific situation.	Noting the angles of incidence and reflection for light rays incident upon a plane mirror.
Verifying	Repeating measurements to check on their accuracy, and corroborating previously obtained results.	Measuring the angle of refraction in a medium for numerous angles of incidence and comparing the calculated values of the index of refraction with each other and with a known standard and determining percent error.

Appendix C

ATTITUDES

1. Appreciating the natural world.
   1.1 Appreciating the natural world, its complexity and diversity, its lawfulness and consistency, and its intricate detail and vastness. For example:
   - Acknowledging the differences, similarities, and interdependencies in nature.

   1.2 Appreciating the natural world as an essential resource in fulfilling human needs, both physical and aesthetic. For example:
   - Conserving natural resources.
   - Admiring beauty in the natural environment.

2. Wanting to know about and understand the natural world.
   2.1 Wanting to know concepts, terms, techniques, and conventions useful in understanding the natural world. For example:
   - Asking about the meaning of terms.
   - Trying to learn how to use measuring instruments.

   2.2 Wanting accurate and thorough information about the natural world. For example:
   - Asking for and looking up factual information.

   2.3 Wanting explanations and interpretations of information that clarify and lead to accurate predictions. For example:
   - Asking for explanations.
   - Questioning explanations.

3. Valuing skepticism, careful investigation, and logical reasoning as means of increasing one's understanding of the natural world.
   3.1 Accepting information and ideas about the natural world as uncertain and valuing verification and supporting reasons. For example:
   - Questioning ideas presented in books or through other media.
   - Testing claims through direct observation, experimentation, and reason.

   3.2 Welcoming the unknown or the ambiguous and accepting contradictory or tentative ideas as starting points for increasing one's understanding of the natural world. For example:
   - Becoming quickly involved in trying to resolve discrepancies in observations or between observations and explanations.
   - Posing problems and puzzles.

   3.3 Valuing original insights, uncertain inferences, and flexible and unconventional thinking as sources of potentially useful ideas. For example:
   - Paying careful attention to new ideas.
   - Presenting original ideas.
   - Willing, for the sake of testing an argument, to accept temporarily an assumption that one believes is false.
   - Understanding and accepting alternative strategies for accomplishing the same task.

   3.4 Valuing careful, systematic investigation as useful in resolving issues. For example:
   - Planning investigations carefully before beginning.
   - Questioning the validity of experiments.

   3.5 Valuing logical reasoning as a means of testing and weighing the validity of ideas. For example:
   - Pointing out flaws in the logic of arguments.
   - Using logic to form and test inferences from data.

4. Respecting others and the environment in pursuing study of the natural world.
   4.1 Valuing the use of investigative procedures that limit the risk to one's self, others, or the living and nonliving environment. For example:
   - Taking safety precautions during investigations.
   - Not injuring plants or animals without justifiable reason.
   - Not disfiguring the environment while studying it.

   4.2 Respecting the rights of others in using resources. For example:
   - Using no more than one's share of common resources.

   4.3 Valuing the contribution of a fair share of the effort in carrying out collaborative studies. For example:
   - Doing one's share of the work in a group project.
   - Contributing ideas in group problem solving.
   - Providing assistance to others in the group when appropriate.

   4.4 Respecting the contributions of others to the solution of a problem. For example:
   - Giving credit to others when using their ideas.
   - Listening to the ideas of others in solving problems.

4.5 Valuing truthful reporting of methods and findings. For example:
- Accurately describing procedures used in gathering data.
- Describing honestly the results obtained from an experiment.

4.6 Respecting the beliefs and values of others in presenting one's own ideas or findings. For example:
- Not ridiculing the ideas of others while presenting one's own ideas.
- Not making remarks which show insensitivity to the beliefs and values of others.

5. Valuing the practical and technological.

5.1 Enjoying working with living and nonliving materials and with scientific techniques or having a high regard for those who do. For example:
- Choosing to work with material things.
- Choosing to construct or take apart mechanical devices.
- Expressing interest in technological occupations.

5.2 Valuing resourcefulness and innovativeness in the solution of practical problems. For examples:
- Attempting to use materials in novel ways to solve problems.
- Complimenting others for expressing innovative ideas.

5.3 Caring about efficiency, simplicity, and dependability of techniques. For example:
- Continually trying to improve techniques by increasing efficiency, simplicity, or dependability.
- Commenting on the efficiency, simplicity, or dependability of techniques or devices.

6. Valuing service to others through technology.

6.1 Valuing the benefits that technological change may have on people and the environment. For example:
- Following technological progress in a field through reading or other media.
- Expressing ideas about potential technological advances that might benefit people or the environment.
- Expressing ideas on how technology can assist handicapped individuals in accomplishing the same tasks as nonhandicapped peers.

6.2 Having concern for the potential adverse consequences of technological change on present and future generations and on the environment. For example:
- Questioning the value of certain technological changes.
- Studying and sharing the problems and dangers that a particular technological change may have on people and on the environment.

are required to demonstrate competency in seven manipulative skills:

1. Demonstrate safety skills involved in handling equipment such as projectiles, chemicals, heating elements, electrical circuits, and radioactive materials.
2. Determine the change in length of a spring as a function of force. Graph the data.
3. Determine the period of a pendulum for a given mass and a given length.
4. Set up a series circuit and a parallel circuit each consisting of a source of potential (battery, power supply) and two resistances (light bulbs, resistors). Determine the current through and potential difference across each resistance and the circuit as a whole.
5. Map a magnetic field using a magnetic compass and a permanent magnet or electromagnet.
6. Determine the path of a light ray passing from air through another medium and back into air using a transparent object (rectangular block, semicircular container). Draw the ray diagram.
7. Formulate inferences about the contents of a "black box" (a sealed system into which one cannot see) by making external observations. Examples of "black boxes" include:
   a) Light rays entering and emerging from a box containing unknown optical components. Students identify the instruments by observing the path of the light rays entering and leaving the box.
   b) A shoe box containing objects having different properties (i.e., magnetic, scent, etc.). Students identify the contents through the use of appropriate tools (i.e., compass, nose, etc.).

   "Black boxes" enable students to understand the process of modeling more clearly, especially as it relates to the development of the model of the atom. An exciting activity is to have the students design the "black boxes."

The Evaluation Plan for assessing proficiency in these seven skills consists of these two components:

1. written responses on the Regents examination, and
2. laboratory performance in the local school setting.

The seven manipulative skills are best assessed by the teacher observing students in the local school setting. **It is the responsibility of the teacher to determine that these skills have been demonstrated.** A Physics Laboratory Skill Evaluation form is included in Appendix B. As each skill is satisfactorily completed, the date and the initials of both the teacher and student are to be recorded on the evaluation form. Satisfactory completion of all seven skills is required prior to admittance to the Regents examination. These completed forms must be filed with the student's written record of laboratory work for a period of six months after the completion of the course.

Safety Suggestions

1. Students should not handle chemicals or equipment in the laboratory until they have been given specific instructions.
2. Students should report at once any equipment in the laboratory that appears to be unusual such as broken, cracked, or jagged apparatus, or any reactions that appear to be proceeding in an abnormal fashion.
3. Students should report any personal injury or damage to clothing to the teacher immediately no matter how trivial it may appear.
4. Loose clothing and hair should be prevented from coming in contact with any science apparatus, chemicals, or sources of heat or flame.
5. Laboratory materials should not be transported through hallways by unsupervised students or during the passing of classes.
6. Students should be instructed never to taste, or inhale directly, unknown chemicals.
7. Students should be warned of the dangers involved in the handling of hot glassware or other equipment. Proper devices for handling these items should be available.
8. Electrical wiring should be checked for fraying, exposed wires, and loose connections.
9. Students should be familiar with the location and use of the fire blanket, fire extinguisher, and eye baths.
10. Students should wear safety glasses whenever chemical or projectile labs are being performed.
11. Students should be given instructions on the proper use of electrical equipment.
12. Appropriate, specific safety instructions should be given which are applicable to particular experiments.

Changes in the Syllabus

Corrections or changes in the syllabus that become necessary will be brought to the attention of school principals by means of supervisory letters from the Department.

total score on the examination. Part II consists of six groups of 10 multiple-choice questions. Each group is based on one of the optional areas, units VI through XI. Students will choose two of the six optional areas in part II, which accounts for 20% of the total score. Part III consists of free-response questions based on the core, units I through V, and accounts for 10% of the total score. For information about free-response questions, see Appendix D.

All students must be provided with a centimeter ruler and a protractor for the Regents examination. Students may use calculators for the examination provided all students in the physics class have access to a calculator during the examination.

Laboratory

The pragmatic approach of "learning by doing" is inherent in a physics course using the laboratory investigations approach. The knowledge obtained by students from meaningful manipulation of laboratory materials can have a profound effect upon their lives by increasing their awareness of the environment of which they are a part. The importance of laboratory work is highlighted by the need to:

1. Stimulate the development of basic skills by providing experiences in recording and interpreting data and manipulating equipment.
2. Develop safety habits which are transferable to everyday situations in and out of school.
3. Provide first-hand experiences with some of the ways in which scientists collect, organize, and interpret data under controlled conditions.
4. Provide some first-hand experiences using activities which are associated with a variety of science-related careers.
5. Stimulate and maintain student interest while developing and reinforcing understandings basic to the course.
6. Foster the attitude that physics is learnable and applicable to the lives of students.

The laboratory can be defined as the place where physics students engage in the manipulation of concrete objects. Manipulative activities provide direct experiences for the students and enable them to answer important questions on the basis of personal observation and experimentation. When planning laboratory experiences, priority should be given to field and laboratory activities which feature manipulation. On rare occasions, there are legitimate instances when nonmanipulative activities can and probably should be substituted for these hands-on activities. The less direct experiences available through filmloops, videotapes, videodiscs, photographs, teacher demonstrations, and microcomputer simulations can be reasonably substituted when the objects or energy levels are sufficiently hazardous, the activity is excessively costly, or the equipment is inaccessible. These situations represent the exception, and should comprise no more than 15% (4.5 periods) of the minimum laboratory requirement of thirty 40-minute periods.

Laboratory investigations should take many forms. In addition to exercises which simply require verification of known constants or relationships using an established procedure, students should also be encouraged to design their own method for a particular investigation and to determine which variables affect the results. In some cases, teachers will find it appropriate for a laboratory experience to precede classroom discussion, while on other occasions laboratory work can be used as an effective follow-up activity. It is vital that laboratory and class work be carefully integrated. Furthermore, teachers are encouraged to provide students with numerous opportunities for hands-on activities, not only during the laboratory, but throughout the physics course.

Regents physics has a mandated laboratory requirement, and successful completion of this course earns for the students one unit of credit in a laboratory science. Each student must be engaged in laboratory activities for at least thirty 40-minute periods (or its equivalent of 1200 minutes) exclusive of time used in changing classes or teachers. Satisfactory written reports of these laboratory experiences must be prepared by the student. Standards for satisfactory written reports must be established by the local school district at the beginning of the school year. At the completion of the course, these laboratory reports must be kept in the school for six months following the date of the examination, except in instances where a senior or transferring student needs these reports for further work.

Pursuant to Section 207 of the Education Law, Section 8.2(c) of the Rules of the Board of Regents states, "Only those persons who have satisfactorily met the laboratory requirements as stated in the State syllabus for a science shall be admitted to the Regents examination in such science." This Rule of the Board of Regents applies to all students whether regularly enrolled in a Regents science class or studying independently. For students with severe physical or emotional handicaps, admission to a Regents science examination without having completed the laboratory requirement will be considered on an individual basis. Questions pertaining to this matter should be directed to the Chief of the Bureau of Science Education, State Education Department, Albany, New York 12234.

The emphasis placed on the laboratory component of this course requires that the teacher be able to evaluate student competencies in the laboratory. In addition to the skills listed above and described in Appendix B, students

Teachers are encouraged to set their own time allotments based on their teaching experience and on student interest and achievement. Below is a suggested time frame based on the idea that this syllabus represents a survey course in physics in which many topics should be given equal treatment.

Mechanics–9 weeks
Energy–3 weeks
Electricity and Magnetism–8 weeks
Wave Phenomena–7 weeks
Modern Physics–2 weeks

Each Optional Area–2 weeks

Organization of the Syllabus

The syllabus is divided into the five core units and six optional units. The core units are:

Mechanics
Energy
Electricity and Magnetism
Wave Phenomena
Modern Physics

The optional units are:

Motion in a Plane
Internal Energy
Electromagnetic Applications
Geometric Optics
Solid State Physics
Nuclear Energy

The syllabus is organized under three major headings in three columns.

1. **Content Outline/Understandings/Concepts**

   This column contains the topical outline and basic concepts of the course and lists quantitative requirements. Concepts in this column are subject to testing on parts I and III, if core, or part II, if optional, of the Regents examination. The asterisk (*) used in the outline denotes that quantitative treatment is required.

2. **Discrepancies/Practical Applications/Activities**

   This column contains discrepancies in italics and practical applications and gives additional information including Unifying Themes, special activities related to the development of skills, and requirements for a course based on this syllabus. Material contained in this column is subject to testing on parts I and III, if core, or part II, if optional, of the Regents examination.

   Discrepancies and practical applications do not have to be memorized by students, but references to them and questions about them may appear on the Regents examination.

3. **Supplementary Information**

   This column includes additional information and explanation of the basic concepts. The material in this column is *not* subject to testing.

Prerequisites

Students enrolling in the Regents physics course must have satisfactorily completed sequential mathematics Course I. They should have also completed or at least be currently enrolled in sequential mathematics Course II. Application of mathematical skills is stressed frequently in this syllabus. Some of this material will already have been developed in courses in mathematics and science. Other topics, such as vectors, may not have been previously studied. **Teachers are encouraged to review mathematical skills and present new mathematical concepts when introducing the associated physics material, rather than spending the first week or two in math review.** For more information, see Appendix E, Mathematics and Measurement.

Systems of Units

SI (International System) units are used in this syllabus. The fundamental units used are the meter, kilogram, second, ampere, and Kelvin. The fundamental units candela and mole are not used in this syllabus.

Regents examination questions will be in terms of the five fundamental units mentioned above and the appropriate derived units (e.g. newton, joule, volt, etc.) as defined at appropriate points in the syllabus. The only exceptions to this rule are the electronvolt, which is a widely used unit of energy, and the atomic mass unit. While examination questions will be confined to these units, the use of other systems (e.g. CGS and FPS) in class and in the laboratory is encouraged.

Significant Figures and Precision in Measurement

The concept of significant figures is important for precision in measurement, but is difficult for many high school students. It is left to the teacher to determine the depth to which the topic is appropriate for his/her particular students.

Students are expected to understand significant figures in terms of the degree of precision to which a common measuring device can be used. This is subject to testing. See Appendix E, Measurement and Mathematics, for examples of the types of questions a student may be asked on the Regents physics examination. Performing operations with significant figures is not subject to testing.

The Regents Physics Examination

The Regents *Examination in Physics* has three parts. Part I consists of 60 multiple-choice questions based only on the core, units I through V, and accounts for 70% of the