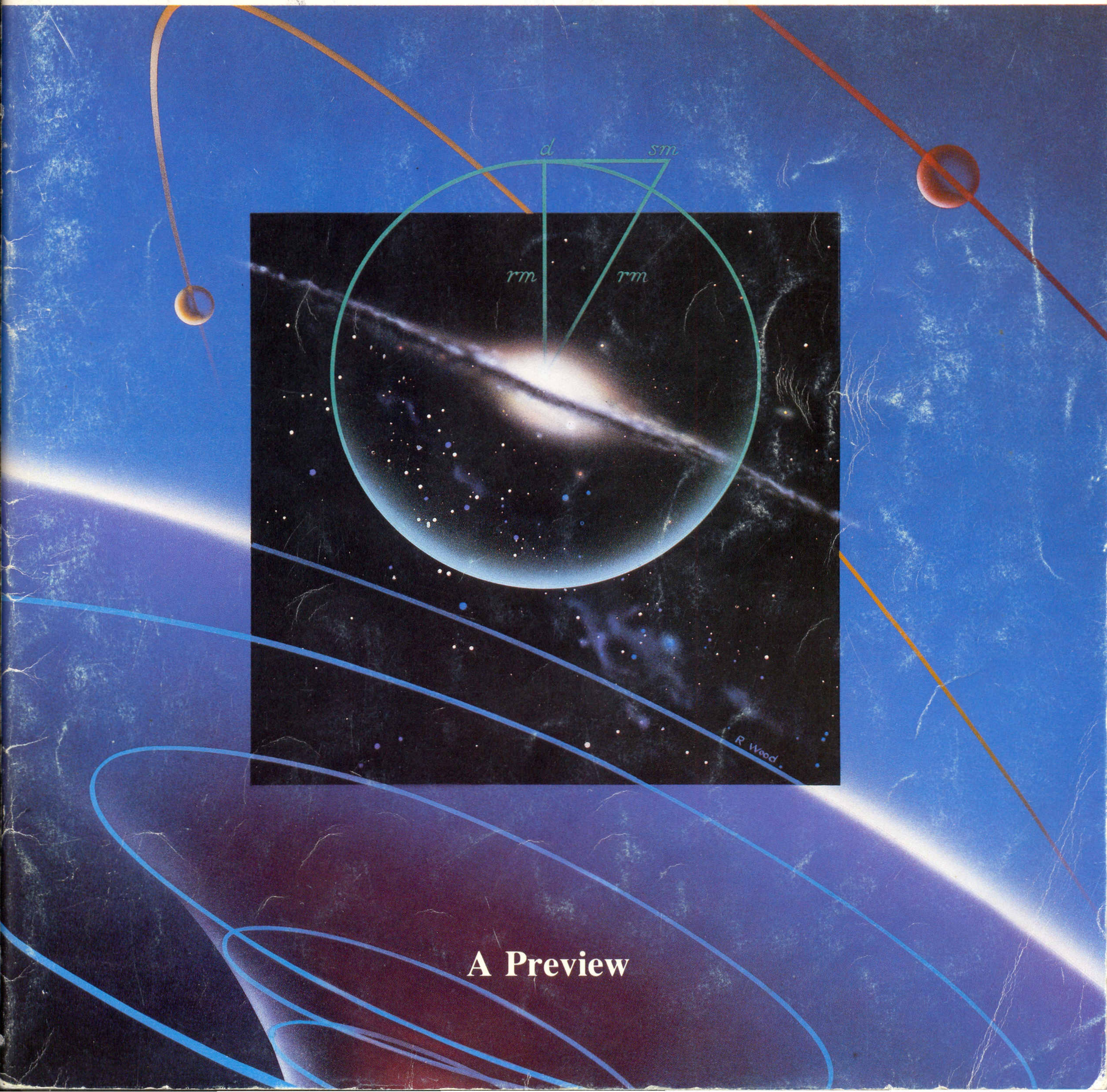
THE MECHANICAL UNIVERSE
. . . and Beyond



A Preview

Part II : ~860

THE MECHANICAL UNIVERSE ...AND BEYOND

An Introductory Physics Television Course

Created and Produced by the California Institute of Technology and the Southern California Consortium

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CONTENTS

INDIVIDUAL LESSON DESCRIPTIONS

THE MECHANICAL UNIVERSE
(Now Available)

Lesson 1: Introduction to THE MECHANICAL UNIVERSE

Provocative questions begin the quest of **The Mechanical Universe**. This introductory preview enters an Aristotelian world in conflict, introduces the revolutionary ideas and heroes from Copernicus through Newton, and, like a space shuttle from past to present, links the physics of the heavens to the physics of the Earth.

Text Assignment: Chapter 1 (Both texts)

Instructional Objectives

- Be able to define the units of length, time and mass.
- Know what is meant by SI units and British units.
- Know what conversion factors are and be able to use them to convert from one system of units into another.
- Be able to express large or small numbers in scientific notation.
- Know common scientific prefixes for units.

Lesson 2: The Law of Falling Bodies

With the conventional wisdom of the Aristotelian world view, almost everyone could see that heavy bodies fell faster than lighter ones. Then along came Galileo. His genius deduced that the distance a body has fallen at any instant is proportional to the square of the time spent falling. From that, speed and acceleration follow with the help of a mathematical tool called a derivative.

Text Assignment: Chapter 2 (Both texts)

Instructional Objectives

- Know the definitions of average speed, average acceleration, speed, and acceleration.
- Recognize that the distance all bodies fall in a vacuum is proportional to the square of the time.
- Recognize that the speed of all falling bodies in a vacuum is proportional to time.
- Recognize that all bodies in a vacuum fall with the same constant acceleration.

- Identify the significant aspects of the historical environment which gave rise to the development of the law of falling bodies.
- Be able to use the following algebraic expressions to solve problems describing the motion of bodies in free fall:

  (a) $s = \frac{1}{2}gt^2$, (b) $v = gt$, (c) $a = g$.
- Understand how the derivative is a limiting process.

Lesson 3: Derivatives

The function of mathematics in physical science. From a theoretical concept to a practical tool, the derivative helps to determine the instantaneous speed and acceleration of a falling body. Differentiation is developed further to calculate how any quantity changes in relation to another. The power rule, the product rule, the chain rule – with a few simple rules, differentiating any function becomes a simple mechanical task.

Text Assignment: Chapter 3 (Both texts)

Instructional Objectives

- Know the definition of a derivative.
- Know the relationship between tangent lines and derivatives.
- Be able to calculate simple derivatives using the rules of differentiation.

Lesson 4: Inertia

The rise of Galileo and his fall from grace. Copernicus conjectured that the Earth spins on its axis and orbits around the sun. Considering its implications, a rather dangerous assumption that prompted rather risky questions: Why do objects fall to Earth rather than hurtle off into space? And in this heretical scheme of things in which the Earth wasn't at the center, where was God? Risking more than his favored status in Rome, Galileo helped to answer such questions with the law of inertia.

Text Assignment: Chapter 4 (Both texts)

Instructional Objectives

- Be able to state the law of inertia.
- Explain situations where the law of inertia applies.
- Distinguish between Aristotle's and Galileo's descriptions of natural motion.
- Recognize that the descriptions of motion are not the same when viewed from different frames of reference.
- Recognize that parabolic trajectories result from constant speed in the horizontal direction and constant acceleration in the vertical direction.
- Appraise the historical significance and universality of Galileo's law of inertia.

Lesson 5: Vectors

Physics must explain not only why and how much, but also where and which way. Physicists and mathematicians invented a way of describing quantities that have direction as well as magnitude. Laws that deal with such phenomena as distance and speed are universal. And vectors, which describe quantities such as displacement and velocity, universally express the law of physics in a way that is the same for all coordinate systems.

Text Assignment: Chapter 5 (Both texts)

Instructional Objectives

- Be able to add and subtract vectors using the parallelogram law of addition.
- Be able to obtain the rectangular components of vectors and use them in addition and subtraction.
- Be able to calculate the dot product of two vectors.
- Be able to form the cross product of two vectors.

Lesson 6: Newton's Laws

For all the phenomena of **The Mechanical Universe**, Isaac Newton laid down the laws. A refinement on Galileo's law of inertia, Newton's first law states that every body remains at rest or continues in uniform motion unless an unbalanced force acts on it. His second law, the most profound statement in classical mechanics, relates the causes to the changes of motion in every object in the cosmos. Newton's third law explains the phenomenon of interactions: for every action, there's an equal and opposite reaction.

Text Assignment: Chapter 6 (Both texts)

Instructional Objectives

- Be able to discuss the definitions of force and mass and to state Newton's laws of motion.
- Be able to distinguish between mass and weight.
- Be familiar with the following units and know how they are defined: kilogram, newton, dyne, pound, slug.
- Know that forces always occur in action-reaction pairs and act on different bodies, so that they never can act as balancing forces for a body.
- Understand that the applicability of Newton's second law arises from it being a differential equation.
- Recognize that projectile motion is a consequence of Newton's laws.

Lesson 7: Integration

Newton and Leibniz sprint for the calculus. Winning the longest race in scientific history – more than 2000 years, from the Golden Age of Greece to the end of the seventeenth century in Europe – Newton and Leibniz arrived at the conclusion that differentiation and integration are inverse processes. Their exciting intellectual discovery, dramatically rerun to reflect the times, ended in an extremely controversial dead heat.

Text Assignment: Chapter 7 (Advanced text – Chapter 3)

Instructional Objectives

- Know the definition of antidifferentiation.
- Understand the relationship between antidifferentiation and quadrature.
- Be able to state the Second Fundamental Theorem of Calculus.
- Know how to apply the Second Fundamental Theorem of Calculus to physics problems.

Lesson 8: The Apple and the Moon

The first authentic steps toward outer space. Seeking an explanation for Kepler's laws, Newton discovered that gravity describes the force between any two particles in the universe. From an English orchard to Cape Canaveral and beyond, Newton's universal law of gravity reveals why an apple but not the moon falls to the Earth.

Text Assignment: Chapter 8 (Advanced text – Chapter 7)

Instructional Objectives

- Recognize that a gravitational force exists between any two objects and that the force is directly proportional to the product of the masses and inversely proportional to the square of the distance between them.
- Understand the functional dependence of the gravitational force on mass and distance.
- Use the following expressions to solve problems: $F = GMm/r^2$, $F = ma$, $a = GM/r^2$.
- Recognize that, for small enough velocities, the time for a projectile to fall to earth is independent of its horizontal velocity, but for very large horizontal velocities, the effect of the earth's curvature must be taken into consideration.
- Describe orbital motion in terms of the law of universal gravitation and inertia.

Lesson 9: Moving in Circles

The original Platonic ideal, with derivatives of vector functions. According to Plato, stars are heavenly beings that orbit the Earth with uniform perfection – uniform speed and perfect circles. Even in this imperfect world, uniform circular motion makes perfect mathematical sense.

Text Assignment: Chapter 9 (Advanced text – Chapters 5 and 7)

Instructional Objectives

- Understand the meaning of uniform circular motion.
- Describe the vector relationships between the radius, velocity, and acceleration in uniform circular motion.
- Be able to use the expressions $a = v^2/r = \omega^2 r = 4\pi^2 r/T^2$ in problems involving circular motion.
- Be able to use Newton's laws to describe the dynamics of circular motion and to solve problems involving objects moving in circular paths.

Lesson 10: The Fundamental Forces

All physical phenomena of nature are explained by four forces. Two nuclear forces – strong and weak – dwell within the atomic nucleus. The fundamental force of gravity ranges across the universe at large. So does electricity, the fourth fundamental force, which binds the atoms of all matter.

Text Assignment: Chapter 10 (Advanced text – Chapter 8)

Instructional Objectives

- Be able to identify which fundamental forces are responsible for a given common force.
- Describe the method Cavendish used to determine the universal gravitational constant G.
- Compare and contrast gravitational and electrical forces.

- Recognize that all contact forces arise from the electrical force acting in complicated ways.
- Be able to apply Newton's laws to solve problems involving pulleys and inclined planes.
- Know that the maximum static friction force and the kinetic friction force are proportional to the normal forces between the surfaces involved.
- Be able to apply Newton's laws in circular-motion problems.

Lesson 11: Gravity, Electricity, Magnetism

Forces at play in the Physics Theater. The gravitational force between two masses, the electric force between two charges, and the magnetic force between two magnetic poles – all these forces take essentially the same mathematical form. Newton's script suggested connections between electricity and magnetism. Acting on scientific hunches, Maxwell saw the matter in an entirely new light.

Text Assignment: Chapter 11 (Advanced text – Chapter 8)

Instructional Objectives

- State one connection between electricity and magnetism.
- Give examples of the concept of "field."
- State some similarities and differences between the force of gravity and electricity.
- Explain how the speed of light is "buried" in the forces of electricity and magnetism.

Lesson 12: The Millikan Experiment

How does science progress? Through painstaking trial and error, illustrated with a dramatic re-creation of Robert Millikan's classic oil-drop experiment. Understanding the electric force on a charged droplet and viscosity, he measured the charge of a single electron.

Text Assignment: Chapter 12 (Advanced text – Chapter 8)

Instructional Objectives

- Be able to describe Millikan's method for measuring the charge of an electron.
- Be able to solve problems with viscous forces.
- Recognize that all charge is a multiple of a fundamental unit of charge, which is the charge of the electron.

Lesson 13: Conservation of Energy

The myth of the energy crisis. According to one of the major laws of physics, energy is neither created nor destroyed.

Text Assignment: Chapter 13 (Advanced text – Chapter 10)

Instructional Objectives

- Know the definitions of work, kinetic energy, and potential energy.
- Understand the relationship between work and energy.
- Be able to work problems using conservation of energy.

Lesson 14: Potential Energy

The nature of stability. Potential energy provides a clue, and a powerful model, for understanding why the world has worked the same way since the beginning of time.

Text Assignment: Chapter 14 (Advanced text – Chapter 10)

Instructional Objectives

- Be able to calculate the potential-energy function associated with a given conservative force.
- Be able to find the force $F(x)$ from the potential-energy function $U(x)$.
- Be able to locate equilibrium points and discuss their stability from a graph of the potential-energy function $U(x)$.
- Be able to use the gravitational potential-energy and conservation of energy to solve the problems of escape velocity.

Lesson 15: Conservation of Momentum

If the mechanical universe is a perpetual clock, what keeps it ticking away till the end of time? Taking a cue from Descartes, momentum – the product of mass and velocity – is always conserved. Newton's laws embody the concept of conservation of momentum. This law provides a powerful principle for analyzing collisions, even at the local pool hall.

Text Assignment: Chapter 19 (Advanced text – Chapter 11)

Instructional Objectives

- Recognize conservation of momentum as a consequence of Newton's Second Law.
- Know when the momentum of a system is conserved.
- Recognize the connection between kinetic energy and momentum.
- Be able to solve problems involving elastic and inelastic collisions.
- Know the relationship between impulse and time average of a force.

Lesson 16: Harmonic Motion

The music and mathematics of nature. The restoring force and inertia of any stable mechanical system cause objects to execute simple harmonic motion, a phenomenon that repeats itself in perfect time.

Text Assignment: Chapter 20 (Advanced text – Chapter 12)

Instructional Objectives

- Know the general characteristics of simple harmonic motion, including the important property that the acceleration is proportional to the displacement and in the opposite direction.
- Know the relationship between simple harmonic motion and circular motion.
- Be able to work problems with objects on horizontal or vertical springs.
- Know the conditions under which the motion of a simple or physical pendulum is simple harmonic and be able to find the period of the motion.
- Understand the connection between simple harmonic motion and energy conservation.

Lesson 17: Resonance

The music and mathematics of nature, Part II. As Galileo noted, the swings of a pendulum increasingly grow with repeated, timed applications of a small force. When the frequency of an applied force matches the natural frequency of a system, large-amplitude oscillations result in the phenomenon of resonance. Resonance explains why a swaying bridge collapsed in a mild wind, and how a wineglass can be shattered by a human voice.

Text Assignment: Chapter 21 (Advanced text – Chapter 12)

Instructional Objectives

- Be able to define forced oscillations.
- Be able to explain resonance and give a few examples.
- Understand the relationship between resonance and forced oscillatory motion.

Lesson 18: Waves

The medium disturbances of nature. With an analysis of simple harmonic motion and a stroke of genius, Newton extended mechanics to the propagation of sound.

Text Assignment: Chapter 22 (Advanced text – Chapter 12)

Instructional Objectives

- Be able to understand the difference between transverse waves and longitudinal waves.
- Be able to state the relationships between the speed, period, frequency, wavelength and angular frequency for a harmonic wave.
- Know the dependence of wave speed on wavelength for deep and shallow water waves.
- Understand why Newton wasn't satisfied with his calculation of the speed of sound.

Lesson 19: Angular Momentum

An old momentum with a new twist. Kepler's second law of planetary motion, which is rooted here in a much deeper principle, imagined a line from the sun to a planet that sweeps out equal areas in equal times. Angular momentum is a twist on momentum – the cross product of the radius vector and momentum. A force with twist is torque. When no torque acts on a system, the angular momentum of the system is conserved.

Text Assignment: Chapter 23 (Advanced text – Chapter 13)

Instructional Objectives

- Know the definitions of torque and angular momentum.
- Know how to write the angular momentum of a system and of a particle.
- Understand the connection between Kepler's second law and the law of conservation of angular momentum.
- Recognize the role of conservation of angular momentum in the formation of vortices and firestorms.

Lesson 20: Torques and Gyroscopes

Why a spinning top doesn't topple. When a torque acts on a spinning object, the angular momentum changes, but the object only precesses. The object may be a child's toy, or a part of a navigation system, or Earth itself.

Text Assignment: Chapter 24 (Advanced text – Chapter 15)

Instructional Objectives

- Be able to explain why a spinning gyroscope precesses instead of falling over.
- Be able to explain how to make a gyroscope with a very small rate of precession.
- Explain how the Earth acts like a gyroscope.

Lesson 21: Kepler's Three Laws

The wandering mathematician. Kepler's three laws described the motion of heavenly bodies with unprecedented accuracy. However, the planets still moved in paths traced by the ancient Greek mathematicians – the conic section called an ellipse.

Text Assignment: Chapter 25 (Advanced text – Chapter 16)

Instructional Objectives

- Understand the historical significance of Kepler's laws.
- Be able to precisely state Kepler's laws.
- Understand the relationship between conic sections and Kepler's laws.
- Know the definition of eccentricity and the formula for a conic section in polar coordinates.

Lesson 22: The Kepler Problem

The combination of Newton's law of gravity and $F = ma$. The task of deducing all three of Kepler's laws from Newton's universal law of gravitation is known as the Kepler problem. Its solution is one of the crowning achievements of Western thought.

Text Assignment: Chapter 26 (Advanced text – Chapter 17)

Instructional Objectives

- Be able to determine velocity in polar coordinates.
- Be able to state the formula for angular momentum in polar coordinates.
- Be able to state the Kepler problem in words.
- Understand how Newton's Laws give a solution to the Kepler problem.

Lesson 23: Energy and Eccentricity

The precise orbit of any heavenly body – a planet, asteroid, or comet – is fixed by the laws of conservation of energy and angular momentum. The eccentricity, which determines the shape of an orbit, is intimately linked to the energy and angular momentum of the heavenly body.

Text Assignment: Chapter 27 (Advanced text – Chapter 17)

Instructional Objectives

- Understand the relationship between energy and eccentricity.
- Be able to characterize orbits by eccentricity.
- Be able to understand the concept of effective potential and how it relates to planetary motion.
- Understand how initial conditions affect the orbit of a planet, comet or satellite.

Lesson 24: Navigating in Space

Getting from here to there. Voyages to other planets require enormous expenditures of energy. However, the amount of energy expended can be minimized by using the same principles that guide planets around the solar system.

Text Assignment: Chapter 28 (Advanced text – Chapter 18)

Instructional Objectives

- Explain how the force of gravity is used in interplanetary travel.
- Discuss the relationship of launch opportunities to planet orbit geometry.
- Distinguish between launch windows to inner and outer planets.
- Be able to calculate periods and velocities for transfer orbits between planets.
- Justify the use of transfer orbits.
- Describe the influence of gravity boosts on a satellite and on the boosting planet.

Lesson 25: From Kepler to Einstein

The orbiting planets, the ebbing and flowing of tides, the falling body as it accelerates – these phenomena are consequences of the law of gravity. Why that's so leads to Einstein's general theory of relativity, and into the black hole, but not back out again.

Text Assignment: Chapter 29 (Advanced text – Chapter 17)

Instructional Objectives

- Understand the derivation of Kepler's third law in planetary calculations.
- Understand the significance of the center of mass of the earth-sun system.
- Understand the causes of tidal motion.
- Understand the difference between inertial mass and gravitational mass.
- Understand qualitatively the concept of a black hole.

Lesson 26: Harmony of the Spheres

The music of the spheres.

Text Assignment: Chapter 30 (No corresponding chapter in the Advanced text)

Instructional Objectives

- Be able to give a brief historical account of the Kepler problem.
- Understand the differences between Aristotle's, Galileo's, Kepler's and Newton's physics.
- Be able to explain why they call mathematics the language of physics.
- Know the significance of conservation principles.
- Explain why some would say that mechanics is the basis of all western knowledge.

BEYOND THE MECHANICAL UNIVERSE
(Available Spring 1987)

Lesson 27: Beyond the Mechanical Universe

Provocative questions begin the quest of **Beyond the Mechanical Universe**. This introductory preview enters the world of Electricity and Magnetism, goes on to 20th-century discoveries of Relativity and Quantum mechanics. The brilliant ideas of Faraday, Ampere, Maxwell, Einstein, Schrödinger, Heisenberg add to **The Mechanical Universe** of Newton.

Text Assignment: Chapter 31

Lesson 28: Static Electricity

To understand materials, one must first understand electricity, and to understand electricity, one must first understand materials. Eighteenth century electricians understood neither, but they knew what it took to spark the interest of an audience and put on an electrifying show. Coulomb's law and the principles of static electricity.

Text Assignment: Chapter 32

Instructional Objectives

- Be able to recognize and discuss electrical phenomena.
- Be able to explain charging by friction, induction and contact.
- Be able to state Coulomb's Law and use it to find the force exerted on one point charge by another.
- Know the difference between an insulator and a conductor.
- Explain ACR, attraction, contact and repulsion.
- Be able to explain the principles of an electrostatic generating machine.

Lesson 29: The Electric Field

Michael Faraday's vision of lines of constant force in space laid the foundation for the modern idea of the field of force. Electric fields of static charges; Gauss' law and the conservation of flux.

Text Assignment: Chapter 33

Instructional Objectives

- Be able to draw lines of force for simple charge systems and to obtain information about the direction and strength of an electric field from such a diagram.

- Know how to calculate the electric field for point charges and simple continuous distributions of charge.
- Know the definition of flux and $1/r^2$ law.
- Be able to state Gauss' law and use it to find the electric field produced by various symmetrical charge distributions.
- Know that a spherically symmetric shell charge distribution produces zero electric field inside the shell and produces a field outside the shell the same as that of a point charge at the center of the shell.
- Be able to explain why the electric field inside a conductor is zero.

Lesson 30: Potential and Capacitance

Benjamin Franklin, the great 18th-century American scientist, who later dabbled in politics, was the first to propose a successful theory of the Leyden Jar. He gave positive and negative charges their names, and invented the parallel plate capacitor. Electrical potential, the potential of charged conductors, equipotentials and capacitance.

Text Assignment: Chapter 34

Instructional Objectives

- Be able to sketch the equipotential surfaces given the electric field in a region.
- Be able to distinguish clearly between electric potential and electric potential energy.
- Know the definition of capacitance and be able to calculate the capacitance for a parallel plate capacitor.
- Be able to state the definition for the energy density for an electric field and discuss the concept of electrostatic field energy.
- Be able to calculate the electrostatic potential energy for a system of point charges.
- Be able to calculate the electric potential for various charge distributions.

Lesson 31: Voltage, Energy and Force

In a world of electric charges and currents, field, forces and voltages, what really matters? When is electricity dangerous or benign, spectacular or useful? The electric potential and its gradient; the potentials of atoms and metals; electric energy, and why sparks jump.

Text Assignment: Chapter 35

Instructional Objectives

- Know the definition of a gradient.
- Be able to state the graphical relationship between electric field lines and equipotentials.
- Be able to state the approximate magnitudes of voltages and forces in matter.
- Know the explanation of how a lightning rod works.
- Be able to give the definition of the electron volt energy unit and the conversion between it and the joule.
- Be able to explain why sparks jump.

Lesson 32: The Electric Battery

Electricity changed from a curiosity to a central concern of science and technology in 1800, when Alessandro Volta invented the electric battery. Batteries make use of the internal properties of different metals to turn chemical energy directly into electric energy.

Text Assignment: Chapter 36

Instructional Objectives

- Be able to understand the internal and external potentials of metals.
- Be able to explain the internal workings of an electric battery.

Lesson 33: Electric Circuits

Design and analysis of currents flowing in series and parallel circuits of resistors and capacitors depend not only on the celebrated laws of Ohm and Kirchhoff, but also on the less celebrated work of Charles Wheatstone.

Text Assignment: Chapter 37

Instructional Objectives

- Be able to state the definitions of current and current density.
- Be able to state Ohm's law and distinguish between it and the definition of resistance.
- Be able to give the general relationship between potential difference, current, and power.
- Know the definitions of parallel and series circuit elements.
- Be able to apply Kirchhoff's rules and use them to analyze various simple *dc* circuits.
- Be able to find the time constant for an RC circuit and describe both the charge on the capacitor and the current as a function of time for charging and discharging a capacitor.

Lesson 34: Magnets

William Gilbert, personal physician by appointment to Her Majesty Queen Elizabeth I of England, discovered that the earth behaves like a giant magnet. Magnetism as a natural phenomenon, the behavior of magnetic materials, and the motion of charged particles in a magnetic field.

Text Assignment: Chapter 38

Instructional Objectives

- Be able to calculate the magnetic force on a current element and on a moving charge in a given magnetic field.
- Know the definition of torque and potential energy for a magnetic dipole.
- Be able to explain the concept of domains in ferromagnetic materials.
- Be able to use the definition of magnetic flux and discuss the significance of the result that the net magnetic flux out of a closed surface is zero.
- Be able to calculate the magnetic moment of a current loop and the torque exerted on a current loop in a magnetic field.
- Be able to discuss the magnetism of the Earth.

Lesson 35: Magnetic Fields

All magnetic fields can be thought to be produced by electric currents. The relationship between a current and the magnetic field it produces is a little peculiar geometrically, and takes some getting used to. The law of Biot and Sarvart, the force between electric currents, and Ampere's law.

Text Assignment: Chapter 39

Instructional Objectives

- Be able to state the law of Biot-Sarvart and use it to calculate the magnetic field due to a straight current-carrying wire and on the axis of a circular current loop.
- Know the definition of Ampere's law and be able to discuss its uses and limitations.
- Be able to calculate the forces between currents.
- Be able to state the various units of magnetic field strength.
- Be able to show that the magnetic field cannot do work.

Lesson 36: Vector Fields and Hydrodynamics

At first glance, replacing the old idea of action at a distance by the new idea of the field of force seems to be an exercise in semantics. But it isn't, because fields have definite properties of their own suitable for scientific study. For example, electric fields are different in form from magnetic fields, and both kinds can better be understood by analogy to fields of fluid flow.

Text Assignment: Chapter 40

Instructional Objectives

- Know the definitions of flux and circulation.
- Be able to relate flux and circulation to the electric, magnetic and velocity flow fields.
- Be able to explain the difference between source and stirring fields.
- Be able to discuss analogies in energy and forces for vector fields.

Lesson 37: Electromagnetic Induction

After Oersted's 1820 discovery that electric currents create magnetism, it was obvious that in some way magnetism should be able to create electric currents. The discovery of electromagnetic induction, in 1831, by Michael Faraday and Joseph Henry was one of the most important of the 19th century, not only scientifically, but also technologically, because it is the means by which nearly all electric power is generated today.

Text Assignment: Chapter 41

Instructional Objectives

- Be able to state Faraday's law and use it to find the *emf* induced by a changing magnetic flux.
- Be able to state Lenz's law and use it to find the direction of the induced current in various applications of Faraday's law.
- Be able to state the definitions of self inductance and mutual inductance.

- Be able to state the expression for the energy stored in a magnetic field and the magnetic energy density.
- Be able to apply Kirchhoff's laws to obtain the differential equation for an LR circuit and be able to discuss the behavior of the solution.

Lesson 38: Alternating Current

Electromagnetic induction makes it easy and natural to generate alternating current. Use of transformers makes it practical to distribute *ac* over long distances. Although Nikola Tesla understood all this, Thomas Edison chose not to, and thereby hangs a tale. Alternating current circuits obey a differential equation identical to the harmonic oscillator resonance equation.

Text Assignment: Chapter 42

Instructional Objectives

- Be able to state the definition of *rms* current and relate it to the maximum current in an *ac* circuit.
- Know the phase relationships between voltages and currents for elements of an LRC circuit.
- Be able to discuss the relationship between an LRC circuit and a harmonic oscillator.
- Be able to describe a step-up and a step-down transformer.
- Be able to discuss the relationship between power transmission and voltage.
- Be able to state the resonance condition for an LRC circuit and to sketch the power versus angular frequency.

Lesson 39: Maxwell's Equations

By the 1860's all the pieces of the electricity and magnetism puzzle were in place, except one. The last piece, discovered by James Clerk Maxwell and called (unfortunately) the displacement current was just what was needed to produce electromagnetic waves called (among other things) light.

Text Assignment: Chapter 43

Instructional Objectives

- Be able to write down Maxwell's equations and discuss the experimental basis of each.
- Be able to state the definition of Maxwell's displacement current and discuss its significance.
- Realize that Maxwell's equations reveal that light is an electromagnetic wave.
- Be able to state the expression for the speed of an electromagnetic wave in terms of electric and magnetic currents.
- Be able to comment on the symmetry of Maxwell's equations.
- Know the significance of Maxwell's equations in modern technological society.

Lesson 40: Optics

Maxwell's theory says that electromagnetic waves of all wavelengths, from radio waves to gamma-rays and including visible light, are all basically the same phenomenon. Many of the properties of light are really just properties of waves, including reflection, refraction and diffraction. Ordinary light can be used to see things on a human scale, X-rays to "see" things on an atomic scale.

Text Assignment: Chapter 44

Instructional Objectives

- Be able to discuss the nature and properties of various parts of the electromagnetic spectrum.
- Be able to state the law of reflection and Snell's law of refraction and relate them to the properties of waves.
- Be able to explain wave interference and diffraction.
- Be able to explain how we can "see" atoms.

Lesson 41: The Michelson-Morley Experiment

In 1887, in Cleveland, Ohio, an exquisitely designed measurement of the motion of the earth through the aether resulted in the most brilliant failure in scientific history.

Text Assignment: Chapter 45

Instructional Objectives

- Know how to apply the Galilean Transformation for coordinates and velocities.
- Be able to describe the Michelson interferometer and explain its principles.
- Be able to state clearly why the Michelson-Morley experiment should have detected motion relative to the aether according to Newtonian Physics.
- Know what is meant by a Null experiment.

Lesson 42: The Lorentz Transformation

If the speed of light is to be the same for all inertial observers (as indicated by the Michelson-Morley experiment) the equations for time and space are not difficult to find. But what do they mean? They mean that the length of a meter stick, or the rate of ticking of a clock depends on who measures it.

Text Assignment: Chapter 46

Instructional Objectives

- Be able to use the Lorentz Transformation to work problems relating time or space intervals in different reference frames.
- Be able to give some of the hypothetical explanations put forward to account for the Michelson-Morley experiment.
- Be able to discuss the concept of length contraction.
- Be able to understand and use spacetime diagrams.
- Be able to define and discuss the concept of simultaneity.
- Be able to define and discuss clock synchronization.

Lesson 43: Velocity and Time

Unlike Lorentz, Albert Einstein was motivated to perfect the central ideas of physics rather than to explain the Michelson-Morley experiment. The result was a wholly new understanding of the meaning of space and time, including such matters as the transformation of velocities, time dilation, and the twin paradox.

Text Assignment: Chapter 47

Instructional Objectives

- Be able to state the Einstein postulates of Special Relativity.
- Be able to state the velocity transformation formula for Special Relativity and how it is different from Galilean relativity.
- Be able to define proper time and proper length and state the equations for time dilation and length contraction.
- Be able to explain the mu-meson experiment in terms of Einstein's theory.
- Know how to use spacetime diagrams for simple problems.
- Be able to clearly state the twin paradox, and discuss its solution.

Lesson 44: Mass, Momentum, Energy

The new meaning of space and time make it necessary to formulate a new mechanics. Starting from the conservation of momentum, it turns out among other things that $E = mc^2$.

Text Assignment: Chapter 48

Instructional Objectives

- Be able to state the definition of relativistic momentum and the equations relating kinetic energy and the total energy of a particle to its speed.
- Be able to discuss the relation between mass and energy in Special Relativity and compute the binding energy of various systems from the known rest masses of their constituents.
- Be able to discuss the concept of relativistic mass.

Lesson 45: Temperature and Gas Law

The ups and downs of scientific research are reflected in Boyle's experiments, and Charles' investigations. Hot new discoveries about the behaviors of gases make the connection between temperature and heat, and raise the possiblity of an absolute scale.

Text Assignment: Chapter 15 (Advanced text – Chapter 19)

Instructional Objectives

- Be able to state the definitions of the Celsius temperature scale and the Fahrenheit temperature scale and convert temperatures given on one scale into those of the other.
- Be able to convert temperatures given on either the Celsius scale or the Fahrenheit scale into kelvins.
- Be able to state the equation of state for an ideal gas and give the value of the universal gas constant in joules per kelvin.

- Know that the average energy of a gas molecule at temperature T is of the order of kT, where k is Boltzmann's constant.
- Know that the absolute temperature T is a measure of the kinetic energy of a gas.

Lesson 46: Engine of Nature

There was young man named Carnot
Whose logic was able to show
For a work source proficient
There's none so efficient
As an engine that simply won't go.
David L. Goodstein, Physics undergraduate (1958)

Text Assignment: Chapter 16 (Advanced text – Chapter 20)

Instructional Objectives

- Be able to state the first law of thermodynamics and use it in solving problems.
- Be able to calculate the work done by a gas during various quasi-static processes and sketch the processes on a PV diagram.
- Be able to give the definition of the efficiency of a heat engine.
- Be able to describe a Carnot engine.
- Be able to use the expression for the efficiency of a Carnot engine.

Lesson 47: Entropy

This program illustrates the genius of Carnot, Part II, and the second law of thermodynamics. The efficiency of Carnot's ideal engine depends on the ratio between high and low temperatures in the running cycle. Carnot's theory begins with simple steam engines and ends with profound implications for the behavior of matter and the flow of time throughout the universe.

Text Assignment: Chapter 17 (Advanced text – Chapter 21)

Instructional Objectives

- Be able to give a qualitative description of entropy.
- Be able to calculate the change in entropy of some irreversible processes.
- Be able to discuss the connection between the second law of thermodynamics and the entropy principle.
- Understand the role of entropy in the formation of ice.

Lesson 48: Low Temperatures

Solids, liquids, and gases are the substance of every substance in the physical world. With the quest for low temperatures came the discovery that, under the right conditions of temperature and pressure, all elements can exist in each of the basic states of matter.

Text Assignment: Chapter 18 (Advanced text – Chapter 22)

Instructional Objectives

- Explain how you make something colder.
- Be able to list and give examples of the three basic states of matter.
- Be able to explain what a phase diagram is.
- Be able to reproduce a phase diagram for water and explain why it is so unique.
- Know how gases are liquefied.
- Be able to explain the Joule-Thomson effect.

Lesson 49: The Atom

This program explores the history of the atom, from the ancient Greeks to the early 20th century, when discoveries by J.J. Thomson and Ernest Rutherford created a new crisis for the world of physics.

Text Assignment: Chapter 49

Instructional Objectives

- Be able to summarize the kinetic theory and discuss the size of atoms.
- Be able to compare Thomson's model of an atom with Rutherford's planetary model of an atom.
- Be able to discuss why Rutherford's model of an atom conflicted with Maxwell's theory of charged particles.
- Be able to discuss the significance of Brownian motion in providing evidence for the existence of atoms.

Lesson 50: Particles and Waves

Even before the crisis of the atom, there was evidence that light, which was certainly a wave, could sometimes act like a particle. In the new physics, called quantum mechanics, not only does light come in quanta called photons, but electrons and other particles also interfere like waves.

Text Assignment: Chapter 50

Instructional Objectives

- Be able to describe the evidence that lightwaves sometimes behave like particles.
- Be able to state the de Broglie relations for the frequency and wavelength of electron waves.
- Be able to discuss wave-particle duality.
- Be able to discuss the Heisenberg uncertainty principle.
- Be able to discuss the experimental evidence for the existence of electron waves.
- Be able to define probability amplitudes and discuss their meaning.

Lesson 51: From Atoms to Quarks

Electron waves confined by electric attraction to the nucleus help resolve the dilemma of the atom and account for the periodic table of the elements. Nucleons themselves obey a kind of period table, following inner rules that lead to the idea of quarks.

Text Assignment: Chapter 51

Instructional Objectives

- Be able to define and discuss standing waves.
- Be able to describe the Bohr atom in terms of standing de Broglie electron waves.
- Be able to discuss the periodic table in terms of electronic structure.
- Be able to discuss quarks and their role in the structure of matter.

Lesson 52: The Quantum Mechanical Universe

A last, lingering look at where we've been, and perhaps a timid glance into the future, marks the close of the series **The Mechanical Universe and Beyond....**

Text Assignment: Chapter 52.