American Association of Physics Teachers

January 18, 2012

Jennifer Childress, Ph.D.
Achieve, Inc.
1400 16th St., NW, Suite 510
Washington, DC 20036

Dear Dr. Childress,

The American Association of Physics Teachers (AAPT) is pleased to see the release of the National Research Council's conceptual framework for new science education standards. The end result is a document that incorporates some of the educational research in teaching and learning over the last 15 years. This document will provide the foundation for engaging students more deeply into understanding, performing, and appreciating science.

We are particularly pleased to see that much of the feedback that AAPT, the American Physical Society and the American Institute of Physics provided on the first draft was incorporated into the version that was released by NRC in mid-July. A select group of K-12 science education experts and AAPT members[1] has reviewed Chapter 5 (Physical Sciences) of the newly released version. This group has collective knowledge of and experience in science and physics education research, writing national standards, developing curricula based on national standards, and writing documents and holding workshops to help physics teachers interpret poorly written state standards. Attached is an edited version of Chapter 5 of the *NRC Framework*, indicating physics errors and inconsistencies in the chapter and key concepts that are missing in the final version, We felt that Achieve would appreciate receiving these errors and inconsistencies that could lead to student misunderstandings as it prepares the *Next Generation Science Standards*. This group of experts has also prepared and sent a list of errors to the NRC to incorporate into a final, edited version of the framework. We include a copy of that letter and list of errors with this letter.

We have also been in consultation with the American Physical Society's Committee on Education about a response to the Framework document. The APS COE is a strong supporter of the move to incorporate the best possible physics for all students such as those outlined in the AAPT response and would be pleased to be a resource for Achieve in its efforts.

AAPT appreciates the opportunity to provide feedback on the framework throughout the process of developing it. We realize that much hard work has occurred in preparing the

[1] Gary Baier, Green Bay East High School; Beverly T. Cannon, Highland Park High School; Dewey Dykstra, Boise State University; Patricia Heller, University of Minnesota; and Drew Isola, Allegan High School

framework but additional work is needed to transform the framework into standards. We look forward to working with Achieve by providing confidential feedback at critical points in the process of developing the new standards.

Sincerely yours,

Beth A. Cunningham, Ph.D.
Executive Officer

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Review: *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*

AAPT and APS, 1/3/2012

1. QUALIFIED TEACHERS GRADES 9-12

The new standards document should clearly state that a detailed understanding by teachers of both chemistry and physics is required if students in grades 9-12 students are to blend the two disciplines into a deeper understanding as recommended by the NRC Framework. In trying to think as a state or local school district official, many of whom do not have a detailed understanding of science, we believe they could take a shortcut by declaring that a generalized "physical science' education in grades K-12 will be good enough at all grade levels. Through grade 8, physical science can and probably should be treated as a unified core discipline. Our concern is that with tight budgets, states and local districts may opt for physical science generalists in grades 9-12. This would defeat the purpose of the Framework where students are to learn the connections between physics and chemistry. Physics and chemistry look at nature from different points of view. A highly trained specialist in physics and/or chemistry is required to meet the goals of the Framework in the area of physical science.

2. CLASSROOM TIME FOR PHYSICS AND CHEMISTRY

Another issue if the merging of three separate disciplines (physics, chemistry, and engineering) into one core area in Chapter 5, Physical Sciences. We are concerned that the two core sciences, which create new knowledge, have to compete for classroom time with engineering/technology. This would be a step backwards, not forwards in advancing science education in the nation. The new standards, as they are developed and implemented, should reflect that chemistry and physics receive an appropriate amount of classroom time.

3. MORE MODERN PHYSICS

Scientific explanation advances sometimes as a gradual accumulation and other times there are major upheavals, sometimes called revolutions. This is one of the fundamental aspects of the nature of science: how we explain the phenomena changes, sometimes significantly. If our curriculum presents only one explanatory system in each science, then the conception that scientific explanations are certain and the explanatory concepts, such as force, energy, atom, sub-atomic particle, gravity, are fixed once and for all, is reinforced. It is as if all the exciting things in science have been done already. If the implications drawn by students from how and what we teach in science is that science is already done, then what is there to invite into science the best, the most ingenious, curious, and inventive students into the sciences?

When we look at the broad temporal span of science, explanatory concepts become profoundly different or are no longer necessary in subsequent formulations. In biology, there has been an on-going "revolution" initiated by the determination of the structure of DNA in the late 1950's. This led to a rework of, and a new basis for understanding, the already established taxonomy of living organisms, our understanding of our origins and our genetic similarities, etc. This change in biology is still going on. In geology, the idea of plate tectonics, and the evidence it explains, has made profound changes in how geologists understand and explain their phenomena. When it was realized, near the beginnings of the 1900's, that atoms had constituent particles, instead of being the smallest, indivisible pieces of matter, it became possible to explain the interactions of atoms in terms of various types of bonding, changing fundamentally how chemists think about matter.

In physics we start by teaching a classical explanatory system, Newtonian mechanics, thermodynamics, and classical electromagnetism. This system is still quite powerful and useful in our everyday world. Yet, at the turn of the last century two major ideas, relativity and quantum mechanics, changed everything about how physicists think about the world. Today, we are on the verge of yet another major revolution in thinking about our world driven by the realization that what we have spent centuries of hard work trying to understand constitutes only about 6% of the universe. Explanations, yet to be constructed, for the other 94% of the universe will profoundly affect our thinking in both physics and astronomy and have repercussions in the other sciences.

Scientific explanations are always tentative and they change in response to encounters with evidence that does not fit the current explanation. Students in all of the sciences and engineering need the chance to realize this essential feature about the nature of science. The rest of the population also needs to realize this to in order to help make decisions of significance to the nation. The conclusion here is that all students need to be exposed to at least one major change in explanatory systems in every science, leaving open the door for them to participate in the coming major revisions in how we explain our world.

Quantum Mechanics. Students could spend some time in high school learning some conceptual, beginning ideas of quantum mechanics and the Standard Model of Subatomic Particles. While some quantum mechanics ideas are abstract and rigorous, the purpose of a conceptual introduction is not deep understanding at the level of manipulating probability functions. The purpose is to leave students with the modern view that photons and subatomic particles do not have wave-like or particle-like properties – it is the probability amplitudes that are wavelike. This introduction would exclude the historical approach (e.g., wave-particle duality, de Broglie's wavelength) that the research literature shows leaves students with many misconceptions.

Some ideas that could be adapted are included below [from College Ready Physics Standards by P Heller and G. Stewart (http://www.compadre.org/psrc/items/detail.cfm?ID=10310)].

1. The theory called quantum mechanics describes, explains, and predicts subatomic interactions. The quantum mechanical consequences of these interactions are sometimes directly visible on the human scale. In quantum mechanics, *interactions* can be modeled as particle-like or wave-like, depending on the number of ways that the interaction can happen. The evidence for these models includes:

    a. Experiments with light interacting with single or double slits that result in a diffraction pattern or two-source interference pattern, which are characteristic of the interaction of mechanical waves with slits.

    b. Experiments with light interacting with metals (photoelectric effect), which result in data patterns characteristic of the interaction of objects (called photons) with discrete energies interacting with other objects (electrons of the electron-rest of metal atom system);

    c. Experiments with electrons interacting with crystals (whose atomic structure acts like slits) resulting in diffraction or interference patterns, which are characteristic of the interaction of mechanical waves with slits; and

    d. Experiments with high-energy particles interacting with materials that result in data patterns characteristic of the interaction of discrete objects.

2. At the macro (human) scale, the properties of an object are descriptions of how the object interacts with other objects, including measurement instruments, and it appears that the effect of the measuring instrument is insignificant. On the other hand, the properties of objects are among the quantities that define interactions (e.g., charges and masses are part of force laws and energy equations). This paradox causes no difficulty until we reach the scale of very small "objects," like electrons and photons. At this scale, the presence of measurement instruments changes the result of an interaction. We cannot ask questions such as: which slit did the particle

(e.g., electron or a photon) go through? We cannot determine precisely both the momentum and the position of an object at the same time. All we can calculate are probabilities.

3. A simplified quantum- mechanical conceptual model of interactions is that there is a set of rules for adding up the probabilities of all possible paths a particle (e.g., photon, electron, or other subatomic particle) could follow from one location to another. The probabilities have the same mathematical form as a wave that changes with time.

    a. Sometimes the probabilities add in such a way that the final location of a particle is the same as predicted from classical mechanics (e.g., light travels in straight lines, the laws of reflection and the refraction of light).

    b. Sometimes the sum of probabilities result is a probability "cloud" for the final location of the subatomic particle. The thicker the probability cloud, then the more likely (probable) it is to find the subatomic particle at that location at any given time. The thinner the cloud, then the less likely it is to find the particle at that location at any given time. For the two-slit experiment, the probability cloud for a photon or electron is the same as the observed interference pattern.

    c. The electrons in an atom do not orbit the nucleus. The sum of the probabilities for the location of a specific electron in an atom is a probability cloud (called an *orbital*). The shape of the probability cloud differs for different electrons in an atom.

4. There are pairs of quantities that can be measured and obtained individually, but never at the same time (e.g., momentum and position, energy and time). You can know one precisely, but then you will know nothing about the other and vice versa. This is called the principle of complementarity.

5. Light and subatomic particles are not waves at one time and particles at another, nor do they have innate particle-like and/or wave-like properties. They are neither particles nor waves. An analogy for quantum mechanics is the flight of a baseball. The path of the baseball is not due to an innate "ballness" property; the path depends of the interactions of the ball with its surroundings (the air and the Earth), and is different in different surroundings (i.e., in the space station). Similarly, the path of an electron (or photon or other subatomic particle) does not depend on whether the electron is a particle, a wave, or something else. The path depends on the interaction of the electron with its surroundings, including measurement instruments. The path of a particle to some final location is described in terms a set of rules for interactions – classical mechanics "rules" or laws for the baseball, and quantum mechanics rules for summing probabilities for subatomic particles.

6. Since the electron, proton, and neutron were discovered, hundreds of subatomic particles have been identified. For each particle type, there is an antiparticle. Antiparticles look and behave just like their corresponding matter particles, except they have opposite charges. Physicists have developed a theory called the *Standard Model of Fundamental Particles and Interactions* that explains what the world is made of and what holds it together. The theory explains all the hundreds of particles and complex interactions with only 6 quarks, 6 leptons, and force carrier particles (bosons), and four fundamental interactions between particles (gravitational, electromagnetic, strong, and weak interactions).

***Special Relativity*.** Students could spend some time learning some conceptual, beginning ideas of special relativity. The knowledge about the special theory of relativity should be limited to a few consequences of relativity (time dilation, length contraction, addition of velocities, and space-time). The purpose is not deep understanding of relativity, but an introduction to a different way of thinking about space and time. Discussion of evidence would be limited to historical experiments for time dilation and length contraction.

Some ideas that could be adapted are included below [from College Ready Physics Standards]

1. While Newton's laws of motion, including the universal law of gravitation, can be used to explain and predict many physical events and have many practical applications, they are not correct for objects traveling near the speed of light. In these cases, Einstein's special theory of relativity must be applied.

2. Newtonian physics is based on the assumption that space and time are absolute and independent. Newton assumed that space itself is a fixed (stationary) reference frame from which all motion can be determined absolutely, and time is constant, progressing at a fixed rate at all locations in space.

3. Einstein's special theory of relativity overthrows Newtonian notions of absolute space and time, although the effects are only noticeable for objects moving very fast -- a significant fraction of the speed of light. The theory is based on two postulates:

   a. *The Principle of Relativity*. The laws of physics are the same in all uniformly moving coordinate systems (inertial frames of reference). So there is there is no absolute time or motion.

   b. *The Constancy of Speed of Light in Vacuum*. The speed of light in vacuum has the same value *c* in all uniformly moving coordinate systems. So there is no coordinate system that is at absolute rest.

4. The consequences of the special relativity postulates have been experimentally verified (including the Michelson-Morley experiment). For example:

   a. When an object (with mass) is in motion, the passage of time, measured with a clock (including a biological clock like pulse rate), is slowed. Only a person that is in a different frame of reference from the object would be able to detect the slowing of time - as far as the object is concerned, in its frame of reference, the passage of time is the same. This phenomenon is referred to as time dilation.

   b. When an object (with mass) is in motion, its measured length shrinks in the direction of its motion. Only a person that is in a different frame of reference from the object would be able to detect the shrinking - as far as the object is concerned, in its frame of reference, its size remains the same. This phenomenon is referred to as length contraction.

   c. Relative velocities of uniformly moving observers never exceed the speed of light. For example if a rocket is moving at 2/3 of the speed of light relative to an observer, and the rocket fires a missile at 2/3 of the speed of light relative to the rocket, the missile does not exceed the speed of light relative to the observer.

   d. Time cannot be separated from space because the *rate at which time passes depends on an object's velocity relative to the speed of light.* The concept of space-time combines space and time within a single coordinate system, typically with 4 dimensions: length, width, height, and time. The space-time coordinate grid is used to locate "events" rather than just points in space.

4. Units of Measurement

We recommend that the new standards emphasize the SI (metric) units of measurement in grades 3-5. Students should be comfortable using these units before middle school and high school.

5. Physics Errors and Inconsistencies

Finally, we were troubled by the many physics errors and inconsistencies in Chapter 5 (physical Sciences) of the *NRC Framework*. It is important that physics terminology be used correctly and consistently in the new standards to avoid misinterpretations or misunderstandings of both teachers and students. To provide feedback about errors and inconsistencies in the Framework, we have reproduced pages 5-2, 5-3, and 5-7 through 5-22. Suggested changes to the narrative are shown by cross-outs and colored insertions in the narrative. The blue inserts are for physics errors, a list of which was sent to NRC on August 22, 2011. The red inserts are inconsistencies that could cause student misunderstandings. Comments for each suggested change are on the right side of each page.

The historical division between the two subjects of physics and chemistry is transcended in modern science, as the same physical principles are seen to apply from subatomic scales to the scale of the universe itself. For this reason we have chosen to present the two subjects together, thereby ensuring a more coherent approach to the core ideas across all grades. The designation of physical science courses at the high school level as either physics or chemistry is not precluded by our grouping of these disciplines; what is important is that all students are offered a course sequence that gives them the opportunity and support to learn about all these ideas and to recognize the connections between them.

CORE IDEA PS1: MATTER AND ITS INTERACTIONS

How can one explain the structure, properties, and interactions of matter?

The existence of atoms, now ~~verified~~ supported by observation with modern instruments, was first postulated as a model that could explain both qualitative and quantitative observations about matter (e.g., Brownian motion, ratios of reactants and products in chemical reactions). Matter can be understood in terms of the types of atoms present and the interactions both between and within atoms. The states (i.e., solid, liquid, gas or plasma), properties (e.g., hardness, conductivity) and reactions (both physical and chemical) of matter can be described and predicted based on the types, interactions, and motions of the atoms within it. Chemical reactions, which underlie so many observed phenomena in living and nonliving systems alike, conserve the number of atoms of each type but change their arrangement into molecules. Nuclear reactions involve changes in the types of atomic nuclei present and are key to the energy release from the sun and the balance of isotopes in matter.

P H 1/2/12 8:41 PM
Comment: This kind of claim is problematic because it implies that we verify theories, which is not true. We build up a long chain of experimental evidence that *supports* a theory, always looking for experiments that would disprove the theory. After a long time, we accept the theory, knowing that future experiments will modify parts of the theory (e.g., The Standard Model of Subatomic Particles and Interactions).

PS1.A: Structure and Properties of Matter

How do particles combine to form the variety of substances one observes?

While too small to be seen with visible light, atoms have substructures of their own. They have a small central region or nucleus—containing protons and neutrons—surrounded by a larger region containing electrons. The number of protons in the atomic nucleus (atomic number) is the defining characteristic of each element; different isotopes of the same element differ in the number of neutrons only. Despite the immense variation and number of substances, there are only some 100 different stable elements.

Each element has characteristic chemical properties. The periodic table, a systematic representation of known elements, is organized horizontally by increasing atomic number and vertically by families of elements with related chemical properties. The development of the periodic table (which occurred well before atomic substructure was understood) was a major advance, as its patterns suggested and led to the identification of additional elements with particular properties. Moreover, the table's patterns are now recognized as related to the atom's outermost electron patterns, which play an important role in explaining chemical reactivity and bond formation, and the periodic table continues to be a useful way to organize this information.

The substructure of atoms determines how they combine and rearrange to form all of the world's substances. Electrical attractions and repulsions between charged particles (i.e., atomic nuclei and electrons) in matter explain the structure of atoms and the forces between atoms that cause them to form molecules (via chemical bonds), which range in size from two to thousands of atoms (e.g., in biological molecules such as proteins). Atoms also combine due to these forces to form extended structures, such as crystals or metals. The varied properties (e.g., hardness, conductivity) of the materials one encounters, both natural and manufactured, can be understood in terms of the atomic and molecular constituents present and the forces within and between them.

Within matter, atoms and their constituents are constantly in motion. The arrangement and motion of atoms vary in characteristic ways, depending on the substance and its current state (e.g., solid, liquid). Chemical composition, temperature, and pressure affect such arrangements and motions of atoms, as well as the ways in which they interact. Under a given set of conditions, the state and "intensive" properties (e.g., density, elasticity, viscosity) are the same for different bulk quantities of a substance, whereas "extensive" properties (e.g., volume, mass) measure the size of the sample at hand.

Materials can be characterized by their intensive measureable properties. Different materials with different properties are suited to different uses. The ability to image and manipulate placement of individual atoms in tiny structures allows for the design of new types of materials with particular desired functionality (e.g., plastics, nanoparticles). Moreover, the modern explanation of how particular atoms influence the properties of materials or molecules is critical to understanding the physical and chemical functioning of biological systems at the molecular level.

Grade Band Endpoints for PS1.A

By the end of grade 2. Matter exists as different substances (e.g., wood, metal, water), and many of them can be either solid or liquid, depending on temperature. Substances can be described and classified by their observable properties (e.g., visual, aural, textural), by their uses, and by whether they occur naturally or are manufactured. Different properties are suited to different purposes. A great variety of objects can be built up from a small set of pieces. Objects or samples of a substance can be weighed and their size can be described and measured. (Boundary: volume is introduced only for liquid measure.)

By the end of grade 5. Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means (e.g., by weighing or by its effects on other objects). For example, a model showing that gases are made from matter particles that are too small to see and are moving freely around in space can explain many observations including: ~~the impacts of gas particles on surfaces (e.g., of a balloon) and on~~ the inflation and shape of a balloon; observations about larger particles or objects (e.g., wind, dust suspended in air), and the appearance of visible scale water droplets in condensation, fog, and, by extension, also in clouds or the contrails of a jet. The amount (weight) of matter is conserved when it changes form, even in transitions in which it seems to vanish (e.g., sugar in solution, evaporation in a closed container). Measurements of a variety of properties (e.g., hardness, reflectivity) can be used to identify particular substances. (Boundary: At this grade level, mass and weight are not distinguished, and no attempt is made to define the unseen particles or explain the atomic-scale mechanism of evaporation and condensation).

P H 1/2/12 8:41 PM

Comment: The problem is that we do not ***observe*** "the impacts of gas particles on surfaces." We may observe balloons, but the pressure inside the balloons we ***explain*** with a kinetic-molecular model of "gas particles" impacting on the inner (and outer) surface of balloons.

By the end of grade 8. All substances are made from some 100 different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. Pure substances are made from a single type of atom or molecule;

Note: Skipped to page 5-7

and produced all of the more massive atoms from primordial hydrogen. Thus the elements found on Earth and throughout the universe (other than hydrogen and most of helium which are primor~~i~~dial) were formed in the stars by this process.

By the end of grade 12. Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve changes in nuclear binding energies. The total number of neutrons plus protons does not change in any nuclear process. Strong and weak nuclear interactions determine nuclear stability and processes. Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials from the isotope ratios present.

Normal stars "burn out" after having converted all of the material in their cores to iron. Elements more massive than iron are formed by fusion processes only in the extreme conditions of supernova explosions, which explains why they are relatively rare.

CORE IDEA PS2: MOTION AND STABILITY: FORCES AND INTERACTIONS

How can one explain and predict interactions between objects and within systems?

Interactions between any two objects can cause changes in one or both of them. An understanding of the forces between objects is important for describing how their motions change, as well as for predicting stability or instability in systems at any scale. All forces between objects arise from a few types of interactions: gravity, electromagnetism, and the strong and weak nuclear interactions.

PS2.A: Forces, Motion and Momentum

How can one predict an object's continued motion, changes in motion, or stability?

Interactions of an object with another object can be explained and predicted using the concept of forces, which can cause a change in motion of one or both of the interacting objects. An individual force acts on one particular object and is described by its strength and direction. The strengths of forces can be measured and their values compared.

What happens when a force is applied to an object depends not only on that force but also on all the other forces acting on that object. A static object typically has multiple forces acting on it, but they counterbalance one another. If the total force on an object is not zero, however, its motion will change. Sometimes forces on an object can also change its shape or orientation. At the macro scale, the motion of an object subject to forces, as well as the relationship of the forces between two interacting objects, are ~~governed~~ described by Newton's second and third laws of motion. The larger the total force on an object of fixed mass, the larger its acceleration (not velocity) will be, and the larger the mass of an object for a particular total force, the smaller its acceleration (not velocity) will be (Newton's second law). For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law).

Under everyday circumstances, the mathematical expression of Newton's second law accurately predicts changes in the motion of a single macroscopic object of a given mass due to the total force on it. But the second law is not applicable without modification at speeds close to the speed of light. Nor does it apply to objects at the molecular, atomic, and subatomic scale or to an object whose mass is changing at the same time as its speed.

P H 1/2/12 8:41 PM

Comment: The misleading part here is the use of the word "governed." Newton and others for 100 – 200 years thought that way, but now we realize that "laws" governing physical phenomena are more properly referred to as explanatory patterns. Within a certain range Newton's laws of motion are a very good explanation of motion, but we now know where these limits are, which are alluded to in the very next paragraph. So, how can we honestly and properly say these laws ***govern*** the motion?

In addition, Newton's 2nd law is never quite spelled out as the 3rd law is in PS2.A. Two of the chief conceptual difficulties, well documented in the literature, is that people believe force causes velocity and that acceleration is just a fancy word for velocity when an object is speeding up.

For speeds that are small compared with the speed of light, the momentum of an object is defined as its mass times its velocity. ~~Within an isolated system of interacting objects, Newton's laws result in the fact that any change in momentum of one object is balanced by an equal and oppositely directed change in the total momentum of the other objects. Thus total momentum is a conserved quantity.~~ For any system of interacting objects, the total change of momentum within the system is equal to the total transfer of momentum (impulse) into or out of the system. This is the conservation of momentum. In a closed system of interacting objects (no transfer of momentum into or out of the system), the change in momentum of one object is equal to but in an opposite direction to the total change in momentum of the other objects. Newton's laws of motion can be derived from the more fundamental conservation of momentum.

P H 1/2/12 8:42 PM

Comment: The original is misleading because it implies that Newton's second law is more fundamental than the conservation of momentum. The conservation of momentum holds even when Newton's second law does not.

There is also an inconsistency in the definition of conservation of momentum compared to the conservation of energy. Like energy, momentum is always conserved, even when momentum is transferred into or out of a system. ***Conservation should be defined the same way for both momentum and energy.***

~~oppositely directed change in the total momentum of the other objects. Thus total momentum is a conserved quantity.~~

Grade Band Endpoints for PS2.A

By the end of grade 2. Objects pull or push each other when they collide or are connected. Pushes and pulls can have different strengths and directions. Pushing or pulling on an object can change the speed or direction of its motion and can start or stop it. An object sliding on a surface or sitting on a slope experiences a push or pull due to friction between the object and the surface that opposes its motion.

> P H 1/2/12 8:42 PM
> **Comment:** Whether the frictional force exerts a push or a pull depends on students' mental models. Either language should be acceptable at this grade level.

By the end of grade 5. Each force acts on one particular object and has both a strength and a direction. An object at rest typically has multiple forces acting on it, but they counterbalance one another. Forces that are not counterbalanced can cause changes in the object's speed or direction of motion. The patterns of an object's motion in various situations can be observed; when that past motion exhibits a regular pattern, future motion can be from it. (Boundary: technical terms, such as magnitude, velocity, momentum, and vector quantity, are not introduced at this level, but the concept that some quantities need both size and direction to be described is developed.)

By the end of grade 8. ~~Any two interacting objects~~ Two interacting objects can exert forces of equal magnitude on each other in opposite directions (Newton's third law). The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The ~~heavier~~ greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. Forces on an object can also change its shape or orientation. In order to share information with others, all positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference system and arbitrarily chosen units of size.

> P H 1/2/12 8:43 PM
> **Comment:** Not all interactions can be described by forces (e.g., radiant energy interaction between the sun and the earth).

> P H 1/2/12 8:43 PM
> **Comment:** This needlessly confuses mass, weighing, and weight. By the end of 8th grade, students should know how to measure mass, and that mass is not the same as weight (weight is the everyday term we use for the gravitational pull of the Earth on an object).

By the end of grade 12. Newton's second law accurately predicts changes in the motion of macroscopic objects, but it requires revision for subatomic scales or for speeds close to the speed of light. The ~~M~~momentum ~~is a property~~ of an object ~~objects~~, defined for a particular frame of reference, ~~that depends on their mass and speed~~ is the mass times the velocity of the object. (Boundary: No details from quantum physics or relativity are included at this grade level. There is just the observation that, at the relevant scales, multiple phenomena necessitate revisions to Newton's laws and that these two theories developed to provide more adequate explanations.)

In any closed system, total momentum is always ~~conserved~~ constant. If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in momentum of objects outside the system thus maintaining conservation of momentum.

> P H 1/2/12 8:43 PM
> **Comment:** Speed is wrong -- should be velocity (momentum is a vector quantity). Whether momentum is the property of an object depends on the definition of property. Since the momentum of an object can change depending on its interactions, most people would not call it a property of an object. For example, if a person were walking west, most people would not think that walking west is a property of the person.

> AAPT H 1/2/12 8:44 PM
> **Comment:** See last comment for page 5-7 (conservation should be defined the same way for both energy and momentum).

PS2.B: Types of Interactions

What underlying forces explain the variety of interactions observed?

All forces between objects arise from a few types of interactions: gravity, electromagnetism, and strong and weak nuclear interactions. Collisions between objects involve forces between them that can change their motion. Any two objects in contact also exert forces on each other that are electromagnetic in origin. These forces result from deformations of the objects' substructures and the electric charges of the particles that form those substructures (e.g., a table supporting a book, friction forces).

Gravitational, electric, and magnetic forces between a pair of objects do not require that they be in contact. These forces are ~~mediated~~ explained by fields that transfer energy through space and that can be mapped by their effect on an ~~test~~ object (e.g., ~~mass~~ a ball, a charged particle, or a magnet, respectively).

Objects with mass are sources of gravitational fields and are affected by the gravitational fields of all other objects with mass. Gravitational forces are always attractive. For two human scale objects, these forces are too small to observe without sensitive instrumentation. Gravitational interactions are nonnegligible, however, when very massive objects are involved. Thus the ~~force of gravity~~ gravitational force of Earth acting on an object near Earth's surface pulls that object toward the planet's center. Newton's law of universal gravitation provides the mathematical model to describe and predict the effects of gravitational forces between distant objects. These long-range gravitational interactions govern the evolution and maintenance of large-scale structures in the universe (e.g., the solar system, galaxies) and the patterns of motion within them.

Electric forces and magnetic forces are different aspects of a single electromagnetic interaction. Such forces can be attractive or repulsive, depending on the relative sign of the electric charges involved, the direction of current flow, and the orientation of magnets. The forces' magnitudes depend on the magnitudes of the charges, currents, and magnetic strengths as well as on the distances between the interacting objects. ~~All objects with electrical charge or magnetization are sources of electric or magnetic fields and can be affected by the electric or magnetic fields of other such objects~~. All objects with electrical charge and magnetization are sources of electric or magnetic fields respectively. Charged objects can be affected by electric fields and magnetic objects can be affected by magnetic fields. Attraction and repulsion of electric charges at the atomic scale explain the structure, properties, and transformations of matter and the contact forces between material objects (link to PS1.A and PS1.B). Coulomb's law provides the mathematical model to describe and predict the effects of electrostatic forces (relating to stationary electric charges or fields) between distant objects.

The strong and weak ~~nuclear~~ interactions are important inside atomic nuclei. These short-range interactions determine nuclear sizes, stability, and rates of radioactive decay (see PS1.C).

Grade Band Endpoints for PS2.B

By the end of grade 2. When objects touch or collide, they push on one another and can change motion or shape.

By the end of grade 5. Objects in contact exert forces on each other (e.g., applied, friction, ~~pressure~~ drag, and elastic pushes and pulls). Electric, magnetic, and gravitational forces between a pair of objects do not require that the objects be in contact—for example, magnets push or pull at a distance. The sizes of the forces in each situation depend on the properties of the objects and their distances apart and, for forces between two magnets, on their orientation relative to each other. The ~~force of gravity~~ gravitational force of Earth acting on an object near Earth's surface pulls that object toward the planet's center.

By the end of grade 8. Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects. Gravitational forces are

P H 1/2/12 8:45 PM
Comment: The use of the word "mediated" ignores the explanatory nature of the idea (model) of a field in physics – the status of fields as an explanatory concept for action at a distance. The problem of action-at-a-distance was such a problem and unsolved; Newton himself wrote that he "framed no hypotheses" concerning the matter in the Principia. Later, the idea of a field was introduced as a possible way of resolving the dilemma. The idea worked so well that we still use it.

In addition, "test object" leads to the idea that a special object is needed to map fields. Moreover, mass and charge are not objects. This language leads to much confusion among students.

P H 1/2/12 8:45 PM
Comment: Language such as "force of gravity" leads to many student misconceptions.

P H 1/2/12 8:45 PM
Comment: Try to avoid the common misconception that magnets are affected by static electric charges and visa versa.

P H 1/2/12 8:45 PM
Comment: Pressure is not a force – it is a scalar quantity. In addition, students need more than one type of contact force to describe everyday situations in terms of forces.

P H 1/2/12 8:45 PM
Comment: Language such as "force of gravity" leads to many student misconceptions.

always attractive. There is a gravitational force between any two masses, but it is very small except when one or both of the objects have large mass—e.g., Earth and the sun. Long-range gravitational interactions govern the evolution and maintenance of large-scale systems in space, such as galaxies or the solar system, and determine the patterns of motion within those structures.

Forces that act at a distance (gravitational, electric, and magnetic) ~~involve~~ are explained by fields that can be mapped by their effect on an ~~test~~ object (e.g., ~~mass~~ a ball, a charged particle, or a magnet, respectively).

P H 1/2/12 8:47 PM
Comment: See 1st comment on page 5-9.

By the end of grade 12. Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects.

Forces at a distance are ~~mediated~~ explained by fields that can transfer energy through space. Magnets or changing electric fields cause magnetic fields; electric charges or changing magnetic fields cause electric fields. Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. The strong and weak nuclear interactions are important inside atomic nuclei—for example, they determine the patterns of which nuclear isotopes are stable and what kind of decays occur for unstable ones.

P H 1/2/12 8:47 PM
Comment: See 1st comment on Page 5-9. The word "mediated" ignores the status of fields as an explanatory concept for interaction at a distance.

PS2.C: Stability and Instability in Physical Systems
Why are some physical systems more stable than others?

Events and processes in a system typically involve multiple interactions occurring simultaneously or in sequence. The system's stability or instability and its rate of evolution depend on the balance or imbalance among these multiple effects.

A stable system is one in which any small change leads to forces that return the system to its prior state (e.g., a weight hanging from a string). A system can be static but unstable, with any small change leading to forces that tend to increase that change (e.g., a ball at the top of a hill). A system can be changing but have a stable repeating cycle of changes, with regular patterns of change that allow predictions about the system's future (e.g., the earth orbiting the sun). And a stable system can appear to be unchanging when flows or processes within it are going on at opposite but equal rates (e.g., water in a dam at a constant height but with water flowing in that offsets the water flowing out, a person maintaining steady weight but eating food, burning calories, and excreting waste).

Stability and instability in any system depend on the balance of competing effects. A steady state of a complex system can be maintained through a set of feedback mechanisms, but changes in conditions can move the system out of its range of stability (e.g., homeostasis breaks down at too high or too low a temperature). With constant conditions, a system starting out in an unstable state will usually continue to change until it reaches a stable configuration (e.g., the temperatures of hot and cold objects in contact). Stable systems may be static or dynamic. Conditions and properties of the objects within a system affect the rates of energy transfer and thus how fast or slowly a process occurs (e.g., heat conduction, the diffusion of particles in a fluid).

P H 1/2/12 8:47 PM
Comment: A ball rolling down an infinite hill will keep increasing speed forever if there is no air. Thus it is always in an unstable configuration. With air it could reach a terminal velocity. The point is, instability does not necessarily evolve to stability.

When a system has a great number of component pieces, one may not be able to predict much about its precise future. For such systems (e.g., with very many colliding molecules), one can often predict average but not detailed properties and behaviors (e.g., average temperature,

P H 1/2/12 8:48 PM
Comment: In the first sentence, it is not clear what "precise" means. It also seems to give the wrong impression. It is the few body system that is difficult to predict. Adding a greater number of pieces makes a behavior of the system easier to predict. The next statement depends on this point.

motion, and rates of chemical change but not the trajectories or other changes of particular molecules).

Grade Band Endpoints for PS2.C

By the end of grade 2. Whether an object stays still or moves often depends on the effects of multiple pushes and pulls on it (e.g., multiple players trying to pull an object in different directions). It is useful to investigat~~ing~~e what pushes and pulls keep something in place (e.g., a ball on a slope, a ladder leaning on a wall) as well as what makes something change or move.

By the end of grade 5. A system can change as its processes move in one direction (e.g., a ball rolling down a hill), shift back and forth (e.g., a swinging pendulum), or go through cyclical patterns (e.g., day and night). Examining how a system's internal forces change as it moves can help explain the system's patterns of change.

P H 1/2/12 8:48 PM
Comment: It is very difficult to interpret what the second sentence means. For example, what are "internal" forces for a ball rolling down the hill? What are the internal forces for the earth rotating on its axis (day and night)? Interpretation depends on how one defines a system and, in this case, the system is not intuitively obvious to the reader.

A system can appear to be unchanging when processes within the system are going on at opposite but equal rates (e.g., water in a dam is at a constant height because water is flowing in at the same rate that water is flowing out). Changes can happen very quickly or very slowly and are sometimes hard to see (e.g., plant growth). Conditions and properties of the objects within a system affect how fast or slowly a process occurs (e.g., heat conduction).

By the end of grade 8. A stable system is one in which any small change leads to forces that return the system to its prior state (e.g., a weight hanging from a string). A system can be static but unstable (e.g., a pencil standing on end). A system can be changing but have a stable repeating cycle of changes; such observed regular patterns allow predictions about the system's future (e.g., Earth orbiting the sun). Many systems, both natural and engineered, rely on feedback mechanisms to maintain stability, but they can function only within a limited range of conditions. With constant conditions, a system starting out in an unstable state will continue to change until it reaches a stable configuration (e.g., sand in an hourglass).

By the end of grade 12. Systems often change in predictable ways; understanding the forces that drive the transformations and cycles within a system, as well as the forces imposed on the system from the outside, help to predict its behavior under a variety of conditions.

When a system has a great number of component pieces, one may not be able to predict much about its precise future. For such systems (e.g., with very many colliding molecules), one can often predict average but not detailed properties and behaviors (e.g., average temperature, motion, and rates of chemical change but not the trajectories or other changes of particular molecules). Systems may evolve in unpredictable ways when the outcome depends sensitively on the starting condition and the starting condition cannot be specified precisely enough to distinguish between different possible outcomes.

P H 1/2/12 8:48 PM
Comment: The use of the word "unpredictable" sets up a false dichotomy between deterministic and non-deterministic systems. Statistical determinism is a very important idea. Students often have the idea that either you know how each particle behaves or you know nothing.

CORE IDEA PS3: ENERGY

How is energy transferred and conserved?

Interactions of objects can be explained and predicted using the concept of transfer of energy from one object or system of objects to another. The total energy within a defined system changes only by the transfer of energy into or out of the system.

PS3.A: Definitions of Energy

What is energy?

~~Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within the system. That there is a single quantity called energy is due to the remarkable fact that a system's *total* energy is conserved as smaller quantities of energy are transferred between subsystems—or into and out of the system through diverse mechanisms and stored in various ways.~~ That there is a quantity called energy is due to the remarkable fact that the total energy of a system is always conserved in all experiments conducted to date. That is, regardless of the quantities of energy transferred between subsystems, or in and out of the system through diverse mechanisms and stored in various ways, the change in a system's total energy is always equal to the total energy transferred into or out of the system. At the microscopic scale, the energy of a system depends on the motion and interactions of matter and radiation within the system.

At the macroscopic scale, energy ~~manifests itself in~~ is related to our experiences with multiple phenomena, such as motion, light, sound, ~~electrical and magnetic fields,~~ and heat. Historically, different units were introduced for the energy ~~present in~~ of these different phenomena, and it took some time before the relationships among them were recognized. ~~Energy is best understood a~~At the microscopic scale, ~~at which it~~ energy can be modeled as either motions of particles or as stored in fields (which mediate interactions between particles). This last concept includes electromagnetic radiation, a phenomenon in which energy stored in fields moves across space (light, radio waves) with no supporting matter medium.

Motion energy is also called kinetic energy; defined in a given reference frame, it is proportional to the mass of the moving object and grows with the square of its speed. Matter at any temperature above absolute zero contains energy due to the motion of the particles within it. For example, a sound wave is a moving pattern of particle vibrations that transmits energy through a medium, and thermal energy is the random motion of particles (whether vibrations in solid matter or molecules or free motion in a gas) that is shared among all the particles in a system

P H 1/2/12 8:49 PM

Comment: A common misconception is that objects contain heat (i.e., thermal energy is not distinguished from heat energy transfer). Once the difference is understood by students, it is important to use the terms correctly and consistently. Some errors and inconsistencies can be avoided with a limited definition of thermal energy.
A suggested addition to the standards for PS3.A is: "All macroscopic objects (defined quantity of a solid, liquid, or gas) with temperatures above absolute zero have thermal energy. The thermal energy depends on the temperature of the object, the nature of the material, and the mass of the object. [Boundary: Thermal energy is the part of internal energy that is useful to define in everyday situations when changes in internal energy are not accompanied by changes of state or chemical changes. For example, when hands are rubbed together, the mechanical energy transfer (work) results in an *increase* in the thermal energy of the hands.]"

P H 1/2/12 8:51 PM

Comment: The 1st sentence only applies at the atomic level, which should be *explicitly stated*. Most people would not call energy a property of a system. For example, a person is the same whether he is running fast or not. Running is not a property of the person. Moreover, energy transfer terms are also energies in the conservation of energy equation, which are not properties of a system. The 2nd sentence does not follow the first, since it applies at all scales. There is no "single" quantity called energy – transfer terms in the conservation of energy equation are energies. Moreover, it would be easy for a reader to conclude that the total energy of the system is constant (i.e., that conservation means constant).

P H 1/2/12 8:52 PM

Comment: Energy is an abstract concept that does not "manifest itself." Similarly electric and magnetic fields are abstract concepts invented to explain interactions at a distance.

through collisions and interactions at a distance. ~~Stored energy is also called potential energy. Changes in stored energy occur when the relative positions of any two interacting objects are changed.~~ Objects or systems have potential energy when their energy is the same when returned to their original configuration or starting condition, regardless of the path taken. For example, elastic potential energy is associated with objects (e.g., springs, bungee cords) that return to their original shape after they are stretched or compressed. Systems of objects that interact at a distance also have potential energy. This energy is modeled as stored in the field around the attracting or repelling objects. Changes in stored (potential) energy occur when the relative positions of objects interacting at a distance are changed. ~~Any such change in stored energy is inevitably compensated for by changes in motion energy or radiation.~~ Any such changes in stored (potential) energy is inevitably compensated for by changes in motion energy or energy transfers into or out of the system. ~~For example, lifting an object increases the stored energy in the gravitational field between that object and Earth (gravitational potential energy); when the object falls, the stored energy decreases and the object's kinetic energy increases correspondingly. When a pendulum swings, some stored energy is transferred into kinetic energy and back again into stored energy during each swing.~~ For example, when energy is transferred into an Earth-object system by lifting an object to a certain height, the energy stored in the gravitational field between that object and Earth (gravitational potential energy) increases; when the object is released and falls, the gravitational field energy decreases and the object's kinetic energy increases. Energy is also transferred out of the system as the falling object pushes aside and moves the air. When a pendulum swings, some stored (potential) energy is transformed into kinetic energy and back again into stored energy during each swing. The pendulum stops swinging because energy is transferred out of the pendulum system during each swing.

Electric and magnetic fields also ~~contain~~ store energy; any change in the relative positions of charged objects (or in the positions or orientations of magnets) changes the fields between them and thus the amount of energy stored in those fields. When a particle in a molecule of solid matter vibrates, energy is continually being ~~transferred~~ transformed back and forth between the energy of motion and the energy stored in the electric and magnetic fields within the matter. Matter in a stable form minimizes the stored energy in the electric and magnetic fields within it; this defines the equilibrium positions and spacing of the atomic nuclei in a molecule or an extended solid and the form of their combined electron charge distributions (e.g., chemical bonds, metals).

P H 1/2/12 8:52 PM

Comment: Not all stored energy is potential energy – in certain circumstances thermal energy, chemical energy and even motion energy can be considered stored energy, but not potential energy. For example, energy can be stored in a rotating flywheel. Moreover, changes in stored (potential) energy do not occur when the relative positions of ***any*** two interacting objects change – only for objects interacting at a distance. Finally, stored energy is not used consistently in Chapter 5 to mean potential energy. In the new standards, you will have to come up with consistent language for both stored energy and potential energy.

P H 1/2/12 8:52 PM

Comment: This sentence only applies at the atomic scale, which should be *explicitly* stated**.** Moreover, the examples in the next sentences are macroscopic examples, for which this statement *does not apply*.

P H 1/2/12 8:53 PM

Comment: The last part of the first sentence is only true when air resistance is negligible (i.e., no transfers of energy into or out of the system). In addition, most students have difficulty with idealized systems, especially when they contradict their direct experience.

P H 1/2/12 8:53 PM

Comment: The word *transferred* cannot be substituted for *transformed* (or *converted*). Forms of energy are not transferred into other forms of energy. There are several methods by which energy is transferred [e.g., when a force parallel to the direction of motion acts over a distance (work); when two objects/systems are at different temperatures (heat)], and the word *transfer* only refers to these methods.

Sometimes transformed is the right word. You could introduce the circumstances when the word transformation is appropriate – when we do not care or know about the energy transfer mechanisms occurring *within a system*, we say that the form of energy within a system that is decreasing is "transformed" or "converted" into the form of energy that is increasing.

~~Electromagnetic radiation~~ Radiant Energy (such as light and X-rays) can be modeled as a wave of changing electric and magnetic fields (electromagnetic radiation). At the subatomic scale ~~(i.e., in quantum theory)~~, many phenomena involving ~~electromagnetic radiation~~ radiant energy (e.g., photoelectric effect) are ~~best~~ more accurately modeled as a stream of particles called photons. ~~Electromagnetic radiation~~ Radiant energy from the sun is a major source of energy for life on Earth.

> P H 1/2/12 8:53 PM
> **Comment:** Since modeling is a crosscutting concept, it is important to distinguish between the thing being modeled and the model itself. In this case, the thing being modeled is radiant energy – electromagnetic radiation *is one model* of radiant energy.

~~The idea that there are different forms of energy, such as thermal energy, mechanical energy, and chemical energy, is misleading, as it implies that the nature of the energy in each of these manifestations is distinct when in fact they all are ultimately some mixture of kinetic energy, stored energy, and radiation. Furthermore, what is meant by the first three terms above is seldom precisely defined~~. Scientists within and across science disciplines define forms and transfers of energy in different ways depending on the scale (e.g., cosmic, everyday, atomic, subatomic) and the system selected to solve a specific problem. For example, heat is useful to describe an energy transfer between macro scale objects at different temperatures but does not exist at the atomic level. Depending on the scale and specific problem, "electrical energy" may mean energy stored in a battery or energy transferred by electric currents. Chemical energy usually, but not always, refers to energy that can be stored or released in chemical processes. It is ~~likewise~~ misleading to call sound or light a form of energy; they are phenomena that, among their other properties, transfer energy from place to place and between objects. At the atomic scale, energy is ultimately some mixture of kinetic energy, stored energy, and radiation.

> P H 1/2/12 8:53 PM
> **Comment:** These statements (plus the statement that energy is best understood at the atomic scale on the previous page), are biased, and miss the point that the conservation of energy is a fundamental principle that applies for all sciences at all scales (adding conservation of mass-energy), from the cosmos to the subatomic particles that particle physicists study. In addition, these statements leave the wrong impression that the conservation of energy is useless at the macroscopic scale.
>
> Please consider softening the language with something like the inserted sentences.

Grade Band Endpoints for PS3.A

By the end of grade 2. Intentionally left blank.

By the end of grade 5. The faster a given object is moving, the more energy it ~~possesses~~ has. Energy can be moved from place to place by moving objects or through sound, light, or electric currents. (Boundary: At this grade level, no attempt is made to give a precise or complete definition of energy.)

By the end of grade 8. Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed. A system of objects that interact at a distance may also contain stored (potential) energy, depending on their relative positions. ~~For example, energy is stored—in gravitational interaction with Earth—when an object is raised, and energy is released when the object falls or is lowered.~~ For example, the stored (potential) energy in the gravitational field of the Earth and an object increases when the object is lifted, and decreases when the object falls or is lowered. Energy is also stored in the electric fields between charged particles and the magnetic fields between magnets, and it changes when these objects are moved relative to one another. Stored energy is decreased in some chemical reactions and increased in others.

> P H 1/2/12 8:54 PM
> **Comment:** Energy is not stored in the interaction – it is stored in the fields and exists no matter what the location of the object. In the conservation of energy equation, the important consideration is *changes* (increases or decreases) of energy within systems.

> P H 1/2/12 8:54 PM
> **Comment:** This sentence is tacked on, but concern about relative positions does not apply here. Ultimately, you will have to decide on consistent language for stored energy and potential energy.

~~The term "heat" as used in everyday language refers both to thermal motion (the motion of atoms or molecules within a substance) and radiation (particularly infrared and light)~~. In our everyday language, heat refers to both thermal energy (related to the motion of atoms or molecules within a substance) and to heat energy transfers. In science, heat is the energy transferred when two objects or systems are at different temperatures (which includes radiant energy transfers, particularly light and infrared). ~~Temperature is not a measure of energy~~Temperature is a measure of the average kinetic energy of the particles of matter. But temperature is not a measure of the

> P H 1/2/12 8:54 PM
> **Comment:** This paragraph does not address the scientific meaning of the term heat (e.g., consequence of the zeroth law of thermodynamics). ***Students should learn the scientific meaning for the term heat (even if it is often misused in our everyday language and in textbooks).*** See also 1st comment on page 5-12.

total energy (internal energy) of a system; the relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.

By the end of grade 12. ~~Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's *total* energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.~~ That there is a quantity called energy is due to the remarkable fact that the total energy of a system is always conserved in all experiments conducted to date. That is, regardless of the quantities of energy transferred between subsystems, or in and out of the system through diverse mechanisms and stored in various ways, the change in a system's total energy is always equal to the total energy transferred into or out of the system. At the microscopic scale, the energy of a system depends on the motion and interactions of matter and radiation within the system. At the macroscopic scale, energy ~~manifests itself in~~ is related to our experiences with multiple ~~ways~~ phenomena, such as in motion, ~~electrical and magnetic fields,~~ sound, light, and heat. ~~Terms for energy as viewed at this scale are seldom well defined; for example, "mechanical energy" generally refers to some combination of motion and stored energy in an operating machine. "Chemical energy" generally is used to mean the energy that can be released or stored in chemical processes, and "electrical energy" may mean energy stored in a battery or energy transmitted by electric currents.~~ Scientists within and across science disciplines define forms and transfers of energy in different ways depending on the scale (e.g., cosmic, everyday, atomic, subatomic) and the system selected to solve a specific problem. For example, heat is useful to describe an energy transfer between macro scale objects at different temperatures but does not exist at the atomic level. Depending on the scale and specific problem, "electrical energy" may mean energy stored in a battery or energy transferred by electric currents. Chemical energy usually, but not always, refers to energy that can be stored or released in chemical processes. For some problems, it is useful to define mechanical energy as a combination of motion energy and stored energy.

Historically, different units and names were used for the energy ~~present in~~ of these different phenomena, and it took some

P H 1/2/12 8:54 PM
Comment: See 2nd comment on page 5-12

P H 1/2/12 8:55 PM
Comment: See 3rd comment for page 5-12 (energy does not manifest itself).

P H 1/2/12 8:55 PM
Comment: See 2nd comment for this page (page 5-13).

time before the relationships between them were recognized. ~~These relationships are better understood a~~At the microscopic scale, all of the different ~~manifestations~~ forms and transfers of energy can be modeled as either motions of particles or energy stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. ~~Electromagnetic radiation~~ Radiant energy (such as light and X-rays) can be modeled as a wave or as particles.

PS3.B: Conservation of Energy and Energy Transfer

What is meant by conservation of energy?

How is energy transferred between objects or systems?

The total change of energy in any system is always equal to the total energy transferred into or out of the system. This is called conservation of energy. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Many different types of phenomena can be ~~explained~~ described in terms of energy transfers.

P H 1/2/12 8:55 PM
Comment: See 1st comment for page 5-13.

P H 1/2/12 8:55 PM
Comment: Some errors and inconsistencies could be avoided with a simple definition of work as a mechanical energy transfer. Even young children (grades 4-6) have the intuitive notion that when they move their arms to throw a ball, they have transferred something to the ball. [Because forces are usually taught first, they often have the misunderstanding that the force is transferred to the ball.]

A suggested addition to the standards for this section is: "At the macro scale, energy can be transferred when one object exerts a force on another object over some distance (mechanical energy transfer or "work"). The amount of energy transfer depends on the strength of the force parallel to the direction of motion and the distance the force acts. [Boundary: Students do not need to learn positive and negative work.] A mechanical energy transfer into or out of a system can change the motion energy and stored or potential energy in the system.

AAPT H 1/2/12 8:55 PM
Comment: Since systems is an important crosscutting concept and teaching the global conservation of energy with energy transfers is relatively new, it would be helpful to have some language in the new standards similar to the following: "When two objects interact, energy can be transferred from one object to the other. Many phenomena consist of chains of interactions or multiple simultaneous interactions; energy descriptions in these situations depend on the system one is interested in investigating. Transfers of energy can occur between the objects/subsystems within the defined system. Energy can also be transferred into or out of a system whenever objects/subsystems within the defined system interact with objects outside the system."

AAPT H 1/2/12 8:57 PM
Comment: Energy is not a mechanism that helps explain how things happen. It does not help us understand how or why things happen.

~~Mathematical expressions, which quantify how the stored energy in a system depends on relative particle positions and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe the behavior of a system.~~ Mathematical expressions, which quantify changes in the forms of energy within a system and transfers of energy into and out of a system at different scales (e.g., cosmic, everyday, atomic, subatomic) allow the conservation of energy to be used to describe and predict the behavior of a system.

~~When objects collide or otherwise come in contact, the motion energy of one object can be transferred to the motion of the other objects (or to energy stored within them as they are deformed or heated).~~ When objects collide or otherwise come in contact, some of the energy of one object can be transferred to the other objects resulting in a change of their motion energy and the energy stored within them. Evidence of this stored energy might be observed as deformation or a temperature increase. For macroscopic objects, any such process (e.g., collisions, sliding contact) also transfers some of the energy to the surrounding air ~~as sound, radiation, or thermal motion~~ by sound or heat. For molecules, collisions can also result in energy transfers through chemical processes, which increase or decrease the total amount of stored energy within a system of atoms; the change in stored energy is always balanced by a change in total kinetic energy—that of the molecules present after the process compared with the kinetic energy of the molecules present before it.

Energy can also be transferred from place to place by electric charges, which have acquired their energy from the energy of motion (e.g., moving water driving a spinning turbine). Even when a system is isolated (such as Earth in space), energy is continually being transferred into and out of it by radiation.

Heating is another process for transferring energy. ~~Energy moves out of hotter objects and into colder ones, cooling the former and heating the latter.~~ Heat energy transfer occurs when two objects (a defined quantity of a gas, liquid, or solid) are at different temperatures. Energy moves out of higher temperature objects and into lower temperature objects, cooling the former and heating the latter. This transfer happens in three different ways—by conduction within solids, by the flow of liquid or gas (convection), and by radiation, which can travel across space. The processes underlying convection and conduction can be understood in terms of models of the possible motions of particles in matter.

Radiation can be emitted or absorbed by matter. When matter absorbs light or infrared radiation, the energy of that radiation is ~~transferred~~ often transformed into thermal motion of particles in the matter, or, for shorter wavelengths (ultraviolet, X-ray), the radiation's energy is absorbed within and may possibly ionize atoms or molecules within the matter by knocking out an electron.

Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution within the system or between the system and its environment (e.g., water flows downhill, objects that are hotter than their surrounding environment cool down). Any object or system that can degrade with no added energy is unstable. Eventually it will change or fall apart, although in some cases it may remain in the unstable state for a long time before decaying (e.g., long-lived radioactive isotopes).

P H 1/2/12 8:58 PM
Comment: This sentence is only true for specific closed systems. You cannot predict the behavior of a system unless you know the energy transfers into or out of the system. The sentence also contributes to the misconception that the conservation of energy is not useful except when kinetic and potential energies can be defined. In fact, the conservation of energy is useful at different scales and for different kinds of systems. An example is the first law of thermodynamics ($\Delta U = W + Q$), which has no potential or kinetic energies, but has remarkable predictive power.

P H 1/2/12 8:58 PM
Comment: No heat energy transfer occurs within the system. In addition, forms of energy are not transferred (see last comment for page 5-12)

P H 1/2/12 8:58 PM
Comment: Thermal motion is not a transfer of energy, and only applies at the atomic scale. Heat energy transfer includes thermal radiation.

P H 1/2/12 8:58 PM
Comment: The error here is that the most important aspect of heat energy transfer is left out – a heat energy transfer occurs when two objects are at different temperatures (consequence of the zeroth law of thermodynamics). In addition, students often believe that both "heat" and "cold" are transferred.

P H 1/2/12 8:59 PM
Comment: See last comment on page 5-12. The word transferred cannot be substituted for transformation

AA PT 1/2/12 8:59 PM
Comment: If matter absorbs light, then the energy of the matter is increased as per conservation of energy. **Light does not always increase the thermal motion** - an example is a solar cell or semi-conductor where the photon excites an electron from the valence band to the conduction band.
Also, why limit this to visible and IR light - microwaves also can be absorbed by matter as in a microwave oven - a common experience for students.
Generally, if electromagnetic radiation is incident on matter and is absorbed by the matter, then the energy of that matter is increased as per the conservation of energy.

Grade Level Endpoints for PS3.B

By the end of grade 2. Sunlight warms Earth's surface.

By the end of grade 5. Energy is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another, thereby changing their motion. In such collisions, some energy is typically also transferred to the surrounding air; as a result, the air gets heated and sound is produced.

Light also transfers energy from place to place. For example, energy radiated from the sun is transferred to ~~the earth~~ Earth by light. When this light is absorbed, it warms Earth's land, air, and water and facilitates plant growth.

Energy can also be transferred from place to place by electric currents, which can then be used locally to produce motion, sound, heat, or light. The currents have been produced to begin with from the energy of motion (e.g., moving water driving a spinning turbine).

By the end of grade 8. When the motion energy of an object changes, there is inevitably some other change in energy or transfer of energy at the same time. ~~For example, the friction that causes a moving object to stop also heats the object and the surrounding environment.~~ For example, the friction that causes a moving object to stop also results in an increase in the thermal energy of both surfaces. Eventually heat energy is transferred to the surrounding environment as the surfaces cool down. Similarly, to make an object start moving or to keep it moving when friction ~~forces~~ results in a heat energy transfer ~~energy~~ away from it, energy must be ~~provided from~~ transferred into the object by, say, a person pushing or pulling on the object, chemical processes (e.g., burning fuel) or electrical processes (e.g., an electric motor and battery) ~~processes~~.

The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment (i.e., transfers of energy into or out of the system). Heat ~~E~~energy is transferred out of hotter regions or objects and into colder ones by the processes of conduction, convection, and radiation.

By the end of grade 12. Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. Energy cannot be created or destroyed, but it can be transported from one place to another (i.e., ~~and~~ transferred ~~between systems~~ within and across the boundary of a system).

~~Mathematical expressions, which quantify how the stored energy in a system depends on relative particle positions and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior~~. Mathematical expressions, which quantify changes in the forms of energy within a system and transfers of energy into and out of a system at different scales (e.g., cosmic, everyday, atomic, subatomic) allow the conservation of energy to be used to describe and predict the behavior of a system. The availability of energy limits what can occur in any system.

Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). Any object or system that can degrade with no added energy is unstable. Eventually it will do so, but if the energy releases throughout the transition are small, the process duration can be very long (e.g., long-lived radioactive isotopes).

P H 1/2/12 9:00 PM
Comment: Friction is the most complex interaction to select for this example. There is no heat in this situation except the transfer of energy from the object and the surface to the air. If the system includes both surfaces, then friction is not an external force. So the motion energy of the sliding object decreases and the thermal energy of the two surfaces increases. If the system is the sliding object, then friction is an external force. The frictional force causes an internal energy transfer to the surface of the sliding object and the transformation of the object's kinetic energy into the object's internal energy.

P H 1/2/12 9:00 PM
Comment: Why leave out the most common example that students can understand readily?

P H 1/2/12 9:00 PM
Comment: Teachers and students might not know what environment means in this context.

AA PT 1/2/12 9:00 PM
Comment: The transportation of energy from one place to another is the same as the transfer of energy.

P H 1/2/12 9:00 PM
Comment: See 3rd comment for page 5-14.

PS3.C Relationship Between Energy and Forces

How are forces related to energy?

When two objects interact, each one can exert ~~exerts~~ a force on the other. Contact forces between colliding objects, for example, can be seen at the microscopic level to be due to electromagnetic interactions between the surface particles. However, such collisions can often be modeled at the

AA PT 1/2/12 9:01 PM
Comment: See 2nd comment on page 5-8.

macroscopic scale using conservation of energy without having to examine the detailed microscopic forces.

Forces between two objects at a distance ~~indicate that there~~ are explained by the idea of force fields (gravitational, electric, or magnetic) between them. When the two interacting objects change their relative position, the energy in the force fields between them changes. For any pair of objects interacting via a force field, the force on each object acts in the direction such that motion of that object in that direction would reduce the energy in the force field between the two objects.

However, prior motion and other forces also affect the actual direction of motion. Patterns of motion, such as a weight bobbing on a spring or a swinging pendulum, can be understood in terms of forces at each instant or in terms of ~~transfer~~ transformation of energy between the motion energy and one or more forms of stored energy. The pattern of motion eventually stops because some energy is also transferred out of the system during each cycle.

Grade Band Endpoints for PS3.C

By the end of grade 2. ~~A bigger push or pull makes things go faster, and faster motion can cause a bigger change in shape when things collide.~~ Pushing or pulling on an object can change its speed or direction of motion. Faster speeds during a collision can cause a bigger change in shape.

By the end of grade 5. When objects collide, the contact forces transfer energy so as to change the objects' motions. ~~Magnets can exert forces on other magnets or on magnetizable materials, thereby transferring energy (e.g., in the form of motion) even when the objects are not touching~~. Even when they are not touching, magnets can exert forces on other magnets or magnetiizable materials, causing a transfer of energy to the objects that changes their motion.

By the end of grade 8. When two objects interact, each one can exert ~~exerts~~ a force on the other~~,~~ that can cause energy to be transferred to or from each object. ~~and these forces transfer energy between them.~~ ~~For example, gravitational interactions between an object and Earth store energy as the object is raised and release energy as the object falls;~~ For example, the stored energy in the gravitational field of the Earth and an object increases when the object is lifted, and decreases when the object falls or is lowered; magnetic and electric forces between two objects at a distance can result in a transfer of energy between the interacting objects.

By the end of grade 12. Force fields (gravitational, electric, and magnetic) ~~contain~~ store energy and can transmit energy across space from one object to another.
When two objects interacting through a force field change relative position, the energy stored in the force field is changed. Each force between the two interacting objects acts in the direction such that motion in that direction would reduce the energy in the force field between the objects. However, prior motion and other forces also affect the actual direction of motion.

PS3.D: Energy in Chemical Processes and Everyday Life

How do food and fuel provide energy?
If energy is conserved, why do people say it is produced or used?

In ordinary language, people speak of "producing" or "using" energy. This refers to the fact that energy in concentrated form is useful for generating electricity, heat, and light, whereas diffuse energy in the environment is not readily captured for practical use. Therefore, to produce

P H 1/2/12 9:01 PM
Comment: As before a misleading statement about fields is being made. Force fields are used to explain action-at-a-distance. The statement as it is confuses an important distinction between experience and explanation.

P H 1/2/12 9:01 PM
Comment: See last comment on page 5-12: the word cannot be substituted for transformation.

P H 1/2/12 9:01 PM
Comment: People are often confused by idealized systems, especially when they contradict direct experience -- so this sentence was added.

P H 1/2/12 9:01 PM
Comment: Forces do not cause motion; they cause a *change in motion*. It's better not to start misconceptions early.

P H 1/2/12 9:01 PM
Comment: Forms of energy, like motion energy, are not transferred. See last comment on page 5-12.

P H 1/2/12 9:02 PM
Comment: Energy is not stored in the interaction – it is stored in the fields and exist no matter what the location of the object.

energy typically means to convert some stored energy into a desired form—for example, the stored energy of water behind a dam is released as the water flows downhill and drives a turbine generator to produce electricity, which is then delivered to users through distribution systems. Food, fuel, and batteries are especially convenient energy resources because they can be moved from place to place to provide processes that release energy where needed. A system actually “uses” energy when carrying out any beneficial process, although not in the verb’s popular sense. The process cannot occur without energy being available. The energy is also “used up” by the end of the process because it is transferred ~~to~~ by heat to the surrounding environment, in the same sense that paper is “used up” when it is written on; it still exists but is not readily available for further use.

> P H 1/2/12 9:02 PM
> **Comment:** Energy is not transferred ***to*** heat – heat is the name we give to the energy transfer that occurs when two objects are at different temperatures. This language is important to avoid student misunderstandings.

Naturally occurring food and fuel contain complex carbon-based molecules, chiefly derived from plant matter that has been formed by photosynthesis. The chemical reaction of these molecules with oxygen releases energy; such reactions provide energy for most animal life and for residential, commercial, and industrial activities.

Electric power generation is based on fossil fuels (coal, oil, and natural gas), nuclear fission, or renewable resources (solar, wind, tidal, geothermal, and hydro power). Transportation today chiefly depends on fossil fuels, but the use of electric and alternative fuel (hydrogen, biofuel) vehicles is increasing. All forms of electricity generation and transportation fuels have associated economic, social, and environmental costs and benefits, both short and long term. Technological advances and regulatory decisions can change the balance of those costs and benefits.

Although energy cannot be destroyed, it can be converted to less useful forms. In designing a system for energy storage, energy distribution, or to perform some practical task (e.g., to power an airplane), it is important to design for maximum efficiency—thereby ensuring that the largest possible fraction of the energy is used for the desired purposes rather than being transferred out of the system in unwanted ways (e.g., through friction, which ~~heats~~ eventually results in a heat energy transfer to the surrounding environment). Improving efficiency reduces costs, waste materials, and many unintended environmental impacts.

> P H 1/2/12 9:03 PM
> **Comment:** Friction increases the thermal energy of the surfaces. Eventually, heat is transferred to the surrounding objects as the surfaces cool down.

Grade Band Endpoints for PS3.D

By the end of grade 2. ~~When two objects are rubbed together heat is produced; this is called friction.~~ When the surfaces of two objects rub against each other, this interaction is called friction. Friction between two surfaces can increase the temperature of the surfaces (e.g., rubbing hands together). There are ways to reduce the friction between two objects.

> P H 1/2/12 9:03 PM
> **Comment:** Heat is not “produced” in this process, and the production of heat is not called friction.

By the end of grade 5. The expression “produce energy” typically refers to the conversion (transformation) of stored energy into a desired form for practical use—for example, the stored energy of water behind a dam is released so that it flows downhill and drives a turbine generator to produce electricity. ~~Food and fuel also release~~ Eenergy is released when ~~they~~ fuel and food are burned or digested. When machines or animals “use” energy (e.g., to move around), most often the energy finishes up transferred ~~to~~ by heat to ~~in~~ the surrounding environment.

> P H 1/2/12 9:03 PM
> **Comment:** Food and fuel do not release their energy – the energy released is the energy of the food or fuel *and* oxygen system (combined). Again, language is important.

The energy released by burning fuel or digesting food was once energy from the sun that was captured by plants in the chemical process that forms plant matter (from air and water). (Boundary: The fact that plants capture energy from sunlight is introduced at this grade level, but details of photosynthesis are not.)

It is important to be able to concentrate energy so that it is available for use where and when it is needed. For example, batteries are physically transportable energy storage devices, whereas electricity generated by power plants is transferred from place to place through distribution systems.

By the end of grade 8. The chemical reaction by which plants produce complex food molecules (sugars) requires an energy input (i.e., from sunlight) to occur. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and release oxygen. (Boundary: Further details of the photosynthesis process are not taught at this grade level).

Both the burning of fuel and cellular digestion in plants and animals involve chemical reactions with oxygen that release stored energy. In these processes, complex molecules containing carbon react with oxygen to produce carbon dioxide and other materials.

Machines can be made more efficient, that is, require less fuel input to perform a given task, by reducing friction between their moving parts and through aerodynamic design. Friction increases energy transfer to the surrounding environment by heating the affected materials.

By the end of grade 12. Nuclear fusion processes in the center of the sun release the energy that Earth receives through radiation. The main way in which that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. Solar cells are human-made devices that likewise capture the sun's energy and produce electrical energy.

A variety of multistage physical and chemical processes in living organisms, particularly within their cells, account for the transport and transfer (release or uptake) of energy needed for life functions.

All forms of electricity generation and transportation fuels have associated economic, social, and environmental costs and benefits, both short and long term.

Although energy cannot be destroyed, it can be converted to less useful forms—for example, to ~~heat~~ thermal energy in the surrounding environment. Machines are judged as efficient or inefficient based on the amount of energy input needed to perform a particular useful task. Inefficient machines are those that produce more waste heat while performing the task and thus require more energy input. It is therefore important to design for high efficiency so as to reduce costs, waste materials, and many environmental impacts.

P H 1/2/12 9:04 PM
Comment: This is an incorrect use of the term heat in this context.

CORE IDEA PS4: WAVES AND THEIR APPLICATIONS IN TECHNOLOGIES FOR INFORMATION TRANSFER

How are waves used to transfer energy and information?

Waves are a repeating pattern of motion that transfers energy from place to place without overall displacement of matter. ~~Light and sound are wavelike phenomena~~. Sound is a wave phenomenon and light can be modeled as electromagnetic waves. By understanding wave properties and the interactions of electromagnetic radiation with matter, scientists and engineers can design systems for transferring information across long distances, storing information, and investigating nature on many scales—some of them far beyond direct human perception.

P H 1/2/12 9:04 PM
Comment: Sound ***is*** a wave, but light can only be modeled as a wave. See also 1st comment for page 5-13.

PS4.A: Wave Properties

What are the characteristic properties and behaviors of waves?

Whether a wave in water, a sound wave, or ~~a~~ light modeled as a wave, all waves have some features in common. A simple wave has a repeating pattern of specific wavelength, frequency, and amplitude. The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which, for each type of wave, depends on the medium in which the wave is travelling. Waves can be combined with other waves of the same type to produce complex information-containing patterns that can be decoded at the receiving end. Waves, which transfer energy and any encoded information without the bulk motion of matter, can travel unchanged over long distances, pass through other waves undisturbed, and be detected and decoded far from where they were produced. Information can be digitized (converted into a numerical representation), sent over long distances as a series of wave pulses, and reliably stored in computer memory.

Sound is a pressure wave in air or any other material medium. The human ear and brain working together are very good at detecting and decoding patterns of information in sound (e.g., speech and music) and distinguishing them from random noise.

Resonance is a phenomenon in which waves add up in phase (i.e., matched peaks and valleys), thus growing in amplitude, due to wave reflections. Structures have particular frequencies at which they resonate when some force acting on them provides energy to them. This phenomenon (e.g., waves in a stretched string, vibrating air in a pipe) is used in the design of all musical instruments and in the production of sound by the human voice.

When a wave passes an object that is small compared with its wavelength, the wave is not much affected; for this reason, some things are too small to see with visible light, which is a wave phenomenon with a definite wavelength for each color. When a wave meets the surface between two different materials or conditions (e.g., air to water), part of the wave is reflected at that surface and another part continues on, but at a different speed. The change of speed of the wave when passing from one medium to another can cause the wave to change direction or refract. These wave properties are used in many applications (e.g., lenses, seismic probing of the earth).

Grade Band Endpoints for PS4.A

By the end of grade 2. Waves, which are regular patterns of motion, can be made in water by disturbing the surface. When waves move across the surface of deep water, the water goes up and down in place; it doesn't move in the direction of the wave—observe, for example, a bobbing cork or seabird—except when the water meets the beach. Sound can make matter vibrate, and vibrating matter can make sound.

By the end of grade 5. Waves of the same type can differ in amplitude (height of the wave) and wavelength (spacing between wave peaks). Waves can add or cancel one another as they cross, depending on their relative phase (i.e., relative position of peaks and troughs of the waves), but they emerge unaffected by each other. (Boundary: The discussion at this grade level is qualitative only; it can be based on the fact that two different sounds can pass a location in different directions without getting mixed up.)

Earthquakes cause seismic waves, which are waves of motion in Earth's crust.

By the end of grade 8. A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude. A sound wave needs a medium through which it is transmitted.

Geologists use seismic waves and their reflection at interfaces between layers to probe structures deep in the planet.

By the end of grade 12. The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing. The reflection, refraction, and transmission of waves at an interface between two media can be modeled on the basis of these properties.

Combining waves of different frequencies can make a wide variety of patterns and thereby encode and transmit information. Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses.

Resonance is a phenomenon in which waves add up in phase in a structure, growing in amplitude due to some energy input. Structures have particular frequencies at which they resonate. This phenomenon (e.g., waves in a stretched string, vibrating air in a pipe) is used in speech and in the design of all musical instruments.

PS4.B: Electromagnetic Radiation

What is light?
How can one explain the varied effects that involve light?
What other forms of electromagnetic radiation are there?

~~Electromagnetic radiation~~ Radiant Energy (e.g., radio, microwaves, light) can be modeled as a wave pattern of changing electric and magnetic fields (electromagnetic waves) or, alternatively, as particles. Each model is useful for understanding ~~aspects of the phenomenon and~~ its interactions with matter, and quantum theory ~~relates~~ unites the two models. Electromagnetic waves can be detected over a wide range of energies (frequencies) of which the visible spectrum of colors detectable by human eyes is just a small part. Many modern technologies are based on the manipulation of electromagnetic waves.

All electromagnetic radiation travels through a vacuum at the same speed, called the speed of light. Its speed in any given medium depends on its wavelength and the properties of that medium. At the surface between two media, like any wave, light can be reflected, refracted (~~its path bent~~ its direction changes), or absorbed. What occurs depends on properties of the surface and the wavelength of the light. When ~~shorter wavelength~~ higher frequency (higher energy) electromagnetic radiation (ultraviolet, X-rays, gamma rays) is absorbed in matter, it can ionize atoms and cause damage to living cells. However, because X-rays can travel through soft body matter for some distance but are more rapidly absorbed by denser matter, particularly bone, they are useful for medical imaging. Photovoltaic materials emit electrons when they absorb light of a high-enough frequency. This phenomenon is used in barcode scanners and "electric eye" systems, as well as in solar cells. It is best explained using a particle model of light.

Any object emits a spectrum of electromagnetic radiation that depends on its temperature. In addition, atoms of each element emit and preferentially absorb characteristic frequencies (energies) of light. These spectral lines allow identification of the presence of the element, even in microscopic quantities or for remote objects, such as a star. Nuclear transitions that emit or absorb gamma radiation also have distinctive gamma ray ~~wavelengths~~ frequencies, a phenomenon that can be used to identify and trace specific radioactive isotopes.

Grade Band Endpoints for PS4.B

By the end of grade 2. Objects can be seen only when light is available to illuminate them. Very hot objects give off light (e.g., a fire, the sun).

P H 1/2/12 9:04 PM
Comment: See 1st comment for page 5-13. Quantum theory does not relate the two models, it unites the two models into a new model or theory. It is the probability amplitudes that are wave-like – photons do not have some wave properties and some particle properties. All of their properties are quantum mechanical.

P H 1/2/12 9:04 PM
Comment: While the term "bend" is common when referring to refraction, it can lead to misconceptions (e.g., curved bending).

P H 1/2/12 9:04 PM
Comment: In the electromagnetic radiation model of light, energy is directly related to the frequency (inversely to the wavelength). So frequency should be used whenever it is the energy of the radiation that is important.

AAPT H 1/2/12 9:05 PM
Comment: See 3rd comment above.

Some materials allow light to pass through them, others allow only some light through, and others block all the light and create a dark shadow on any surface beyond them (i.e., on the other side from the light source), where the light can't reach. Mirrors and prisms can be used to redirect a light beam. (Boundary: The idea that light travels from place to place is developed through experiences with light sources, mirrors, and shadows, but no attempt is made to discuss the speed of light.)

By the end of grade 5. A great deal of light travels through space to Earth from the sun and from distant stars.

An object can be seen when light reflected from its surface enters the eyes; the color people see depends on the color of the available light sources as well as the properties of the surface. (Boundary: This phenomenon is observed, but no attempt is made to discuss what confers the color reflection and absorption properties on a surface. The stress is on understanding that light traveling from the light source to the object to the eye determines what is seen.)

Because lenses ~~bend light beams~~ change the direction of light beams, they can be used, singly or in combination, to provide magnified images of objects too small or too far away to be seen with the naked eye.

By the end of grade 8. When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light.

The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path ~~bends~~ changes direction (except for 90 degrees incidence). Lenses and prisms are applications of this effect.

A wave model of light is useful for explaining brightness, color, and the frequency-dependent ~~bending~~ changing direction of light at a surface between media (prisms). However, because light can travel through space, it cannot be a matter wave, like sound or water waves. (Boundary: Students will ask, "Then what is it?" so the teacher may introduce the idea that ~~light is a wave consisting of regularly changing electric and magnetic fields, but~~ scientists do not know what light *is*. Light can sometimes be modeled as a wave, and sometimes as a particle, but it is neither of these things. Sstudents at this level should not be held responsible for retaining that fact.)

By the end of grade 12. ~~Electromagnetic radiation~~ Radiant energy (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields (electromagnetic waves) or as particles called photons. The wave model is useful for explaining many features of ~~electromagnetic radiation~~ radiant energy, and the particle model explains other features. Quantum theory ~~relates~~ unites the two models. (Boundary: Quantum theory is not explained further at this grade level.)

Because a wave is not much disturbed by objects that are small compared with its wavelength, visible light cannot be used to see such objects as individual atoms. All electromagnetic radiation travels through a vacuum at the same speed, called the speed of light. Its speed in any other given medium depends on its wavelength and the properties of that medium.

When light or ~~longer wavelength~~ lower frequency (lower energy) electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy ~~(heat)~~. ~~Shorter wavelength~~ Higher frequency electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells. Photovoltaic materials emit electrons when they absorb light of a high-enough frequency.

AAPT H 1/2/12 9:05 PM
Comment: See 2nd comment for page 5-20.

AA PT 1/2/12 9:05 PM
Comment: See 2nd comment for page 5-20.

AAPT H 1/2/12 9:05 PM
Comment: See 2nd comment for page 5-20.

P H 1/2/12 9:05 PM
Comment: Electromagnetic waves is only one model of light, and does not reflect the nature of science. Middle school student are perfectly capable of developing a particle like and wave-like model of radiant energy transfer.

AAPT H 1/2/12 9:06 PM
Comment: See 1st comment for page 5-13.

P H 1/2/12 9:06 PM
Comment: See 3rd comment for page 5-20. In addition, thermal energy is not the same as heat (see first comment on page 5-12).

Atoms of each element emit and absorb characteristic frequencies of light, and nuclear transitions have distinctive gamma ray ~~wavelengths~~ frequencies. These characteristics allow identification of the presence of an element, even in microscopic quantities.

AAPT H 1/2/12 9:06 PM
Comment: See 3rd comment for page 5-20.

PS4.C: Information Technologies and Instrumentation

How are instruments that transmit and detect waves used to extend human senses?

Understanding of waves (sound waves and radiant energy modeled as waves) and their interactions with matter has been used to design technologies and instruments that greatly extend the range of phenomena that can be investigated by science (e.g., telescopes, microscopes) and have many useful applications in the modern world.

AAPT H 1/2/12 9:06 PM
Comment: See 1st comment for page 5-13.

Light waves, radio waves, microwaves, and infrared waves are applied to communications systems, many of which use digitized signals (i.e., sent as wave pulses) as a more reliable way to convey information. Signals that humans cannot sense directly can be detected by appropriately designed devices (e.g., telescopes, cell phones, wired or wireless computer networks). When in digitized form, information can be recorded, stored for future recovery, and transmitted over long distances without significant degradation.

Medical imaging devices collect and interpret signals from waves that can travel through the body and are affected by, and thus gather information about, structures and motion within it (e.g., ultrasound, X-rays). Sonar (based on sound pulses) can be used to measure the depth of the sea, and a system based on laser pulses can measure the distance to objects in space, because it is known how fast sound travels in water and light travels in a vacuum. The better the interaction of the wave with the medium is understood, the more detailed the information that can be extracted (e.g., magnetic resonance imaging).

Grade Band Endpoints for PS4.C

By the end of grade 2. People use their senses to learn about the world around them. Their eyes detect light, their ears detect sound, and they can feel vibrations by touch.

People also use a variety of devices to communicate (send and receive information) over long distances.

By the end of grade 5. Lenses can be used to make eyeglasses, telescopes, or microscopes in order to extend what can be seen. The design of such instruments is based on understanding how the path of light bends at the surface of a lens.

Digitized information (e.g., the pixels of a picture) can be stored for future recovery or transmitted over long distances without significant degradation. High-tech devices, such as computers or cell phones, can receive and decode information—convert it from digitized form to voice—and vice versa. (Boundary: At this grade level, no attempt is made to explain these technologies, but students should recognize that “high tech” often connotes applied knowledge of waves, matter, and their interactions.)

By the end of grade 8. Appropriately designed technologies (e.g., radio, television, cell phones, wired and wireless computer networks) make it possible to detect and interpret many types of signals that cannot be sensed directly. Designers of such devices must understand both the signal and its interactions with matter.