Physical Science

Content Standard B:

As a result of the activities in grades 9-12, all students should develop an understanding of

- Structure of atoms
- Structure and properties of matter
- Chemical reactions
- Motions and forces
- Conservation of energy and increase in disorder
- Interactions of energy and matter

Content Summary

National Science Education Content Standards

K-4	5-8	9-12
Properties of objects and materials **Position and motion of objects** **Light, heat, electricity, and magnetism**	**Properties and changes of properties in matter** **Motions and forces** **Transfer of energy**	**Structure of atoms** **Structure and properties of matter** **Chemical reactions** **Motions and forces** **Conservation of energy and increase in disorder** **Interactions of matter and energy**

Minnesota Graduation Standards

Primary Level	Intermediate Level	Middle Level	High School Level
Direct Science Experience: Understand basic science concepts through direct experience	**Living and Non-living Systems:** Understand how individuals and objects interact in life, earth/ space systems and physical systems	**Physical Systems:** Evaluate interactions between physical systems encountered in everyday life	**Concepts in Chemistry:** Understand concepts, theories and principles in chemistry through investigation and analysis **Concepts in Physics:** Understand physics through interactions of matter, forces and energy

Focus K-12

Grade	Early	Late
K-4	The focus of instruction early in this grade range is on providing opportunities for all students to develop an awareness and understanding of the characteristics of objects and materials that they encounter daily through observation, manipulation, and classification.	The focus of instruction later in this grade range is on providing opportunities for all students to observe, describe, and measure properties of objects, the way they change over time, and changes that occur when objects interact.
5-8	The focus of instruction early in this grade range is on providing opportunities for all students to move from understandings about the properties of objects to the characteristic properties of the substances from which objects are made. Basic concepts of force, motion and energy transfer are introduced and explored.	The focus of instruction later in this grade range is on providing opportunities for all students to develop an operational understanding of elements and compounds and characteristic properties of common substances. The concepts of force, motion, and energy are developed through a variety of quantitative experiences.
9-12	The focus of instruction in *chemistry* for all students at the high school level is on providing opportunities to develop an understanding of the relationship among the properties and structure of matter and to explore a variety of chemical reactions and their applications. The focus of instruction in *physics* for all students at the high school level is on providing opportunities to explore, develop, and use physical, conceptual and mathematical models as they develop qualitative and quantitative understanding of force, motion, energy, and matter, and apply their understandings to a variety of situations.	The focus of instruction for students pursuing further study in *chemistry* is on providing opportunities for students to develop a deeper understanding of atomic structure, explore the complex relationships among the structure and properties of matter, including mathematical relationships, and apply their understandings to a variety of situations. The focus of instruction for students pursuing further study in *physics* is on providing opportunities to explore, develop, and use conceptual and mathematical models as they develop a deeper understanding of force, motion, energy, and matter, and apply their understandings to a variety of situations.

Chemistry Close-up 9-12

The focus of instruction in chemistry for all students at the highschool level is on providing opportunities to develop an understanding of the relationship among the properties and structure of matter and to explore a variety of chemical reactions and their applications.

All high school students have studied changes of state, solutions, and simple chemical reactions in the middle grades and have developed enough knowledge and experience to define characteristic properties of substances. Students continue to expand their understanding of the properties of substances and the changes that occur when substances interact. They learn about everyday uses of elements and compounds. They also begin to identify simple periodic patterns and trends. Students separate mixtures using techniques of filtration, distillation, and chromatography, and then identify the components using characteristic properties. They collect quantitative data and use simple algebraic models to develop the concept of density. They may use ordinary household products as they investigate simple chemical reactions. They discover that, while substances change during the reactions, the total mass of the substances does not change. In their study of the interactions of energy and matter, students experiment with endothermic and exothermic reactions and investigate how temperature changes affect the rate of reaction. Research shows that many students at this age still have difficulty comprehending the very small size and scale of the particles involved in reactions, and students may not understand the connection between the particles and chemical formulas that represent them. Concepts such as balanced chemical equations and detailed explanations of chemical bonding are best left to more advanced classes. Students and teachers observe established science safety procedures.

The focus of instruction for students pursuing further study in chemistry is on providing opportunities to develop a deeper understanding of atomic structure, explore the complex relationships among the structure and properties of matter including mathematical relationships, and apply their understandings to a variety of situations.

Students pursuing further study in chemistry work in the laboratory with a variety of practical chemical reactions such as synthesizing and analyzing polymers, titrating common acids and bases, experimenting with electrochemical cells, and measuring temperature changes in exothermic and endothermic reactions. They read original scientific reports and examine the sequence of experiments that led to the current theory of atomic structure. Their study of atomic structure includes electron configurations, quantum theory, chemical bonding, and the analysis of sophisticated periodic trends. They use mathematical concepts to develop their understanding of chemistry. Students' work in the laboratory includes factors that affect rates of reaction including influences of catalysts. Student understanding and ability should allow them to work independently as they investigate these concepts. Students and teachers observe established science safety procedures.

Chemistry On Location 9-12

Kinetic molecular theory (KMT) provides the groundwork for understanding more complex concepts in chemistry such as atomic theory, chemical reactions, bonding, and pressure. Although the vocabulary of atomic theory is often introduced earlier, students rarely fully understand that matter is made of small particles. This vignette illustrates the development of some of the abstract concepts in the KMT. Students are asked to examine their beliefs about matter and then rethink them in light of what happens in a variety of classroom activities.

Ms. R uses a series of hands-on activities to provide her ninth grade students the opportunity to explore matter and gather evidence for its structure. These activities build on students' prior knowledge about the properties of matter. Ms. R begins by having students discuss what they already know and believe about matter. During a class brainstorm activity, Ms. R has a student record all their ideas on the board. The list is diverse, and includes examples of matter, lists of properties, concepts such as volume and mass, along with vocabulary related to atoms. Since most students at least pay lip service to the concept of atoms, Ms. R builds from there, asking them to complete the activities and to analyze the data and evidence from the activities that supports or refutes the particle theory of matter. Ms. R uses the word particles instead of atoms so that the students do not confuse atoms with molecules.

During the brainstorming activity, controversy often arises over whether air is matter. The students conduct activities with a blow dryer and a ping pong ball, and use balloons to actually calculate the mass and volume of air that provide the students with evidence that air is matter. Small group and class conversations are used to clarify data analysis and concepts. For each activity, Ms. R has students draw pictures and write about conclusions based on their evidence. Lively discussions about evidence and conclusions frequently occur as students have their ideas about matter challenged and their understandings about matter change.

Ms. R keeps the attention of the class on questions: What is the evidence? How good is it? What is it about it that supports your conclusions? What else do you need to know?

Other activities used to help students develop their understanding of KMT include mixing coarse sand and fine sand, sand and water, and alcohol and water to show a decrease in volume when the two substances are mixed, diffusion experiments in water and air, expansion and contraction with heat and cold, and paper chromatography with a variety of watercolor markers.

Demonstrations showing that a mylar balloon containing air stays inflated while one filled with helium will completely deflate over time, along with observing bubbles being formed in boiling water, provide more opportunities for discussion and clarification about the particle nature of matter. The compression of air in a large syringe provides a significant challenge for students as they think about what they know and understand about matter. Ms. R reports that she sees many looks of understanding, an "Aha!" when she asks the students what is between the particles of air.

Physics Close-up 9-12

The focus of instruction in physics for all students at the high school level is on providing opportunities to explore, develop, and use physical, conceptual, and mathematical models as they develop qualitative and quantitative understanding of force, motion, energy, and matter, and apply their understandings to a variety of situations.

All high school students expand on their previous experiences and continue to construct their understanding of forces, motion, light, and electricity. Most students at this age believe that even when there is no friction, a force is still acting on an object if it is moving. They also think that friction, not inertia, is the main reason that objects remain at rest or require a force to move. They associate force with motion and have difficulty understanding balanced forces in equilibrium. Through a variety of investigations and instructional interventions, students begin to revise their original misconceptions about motion and forces and develop scientifically acceptable understandings of natural phenomena. They use basic algebraic concepts and graphs as they analyze data and develop quantitative understandings of the concepts of motion and force. Students continue their middle level experiences with energy transfer by measuring variables such as temperature change and heat loss or gain, conduction, radiation and insulation potential of materials, and potential and kinetic energy changes. They conduct investigations and analyze data to develop the concepts of conservation of energy and matter. Through experiences with electromagnets, they investigate the relationship between moving electric charges and magnetic forces and apply their understandings to generators and motors. Interactions of energy and matter are studied using water, light, and sound waves. Students and teachers observe established science safety procedures.

The focus of instruction for students pursuing further study in physics is on providing opportunities to explore, develop, and use physical, conceptual, and mathematical models as they develop a deeper understanding of force, motion, energy, and matter and apply their understandings to a variety of situations.

Students pursuing further studies in physics use more sophisticated problem solving approaches as they develop a quantitative understanding of motion, electrical and gravitational forces, and magnetism. This understanding includes the use of algebraic, trigonometric, and calculus-based relationships. Through a variety of experiences with light waves and modern physics, students develop an understanding of the relationship between energy and matter. Some students might repeat historical experiments such as Millikan's oil drop experiment and J. J. Thompson's mass of an electron. Students' abilities and understandings should allow them to work independently and in small groups as they investigate physics concepts. Students and teachers observe established science safety procedures.

Physics On Location 9-12

The lesson below deals specifically with force and motion within an accelerated frame of reference. Notice how the teacher engages his students with demonstrations that run counter to students' intuition. Often this type of teaching is confused with inquiry. In this lesson the teacher is always in control of the information flow. He uses discrepant events to fuel student interest and to help students reconsider and change their misconceptions about force and motion. Note that it is important that this activity take place in a bus or other vehicle so that everything within the frame of reference, including the air, is moving with the bus.

Students in Mr. N's physics class ride a school bus to study laws of motion. As students load on the bus, they note that a helium-filled balloon on a long string is secured to the floor of the bus. Mr. N asks students to predict what the balloon will do when the driver goes forward. The driver starts the bus and then accelerates. To the surprise of everyone the balloon moves forward while the bus speeds up. Students are again surprised when the balloon moves toward the back of the bus as it slows down. Finally, through a series of questions, the class establishes that the balloon moves in the direction of the acceleration of the bus.

The driver then moves the bus in several directions, and at different speeds. When the bus travels in circles, the balloon shows that the acceleration is toward the center of the circle. Finally, the driver reaches zero velocity by moving slowly forward, then putting the bus in reverse, using the engine of the bus to make it slow down, stop, and then go backward. The balloon never stops pointing toward the back of the bus, indicating that acceleration never reached zero, even though the velocity did.

Back in the classroom, students want to know why the balloon behaved as it did. The teacher then introduces the concept of acceleration. Students are asked, "Imagine how you would feel if the balloon moved forward?" The teacher helps them to understand that according to Newton's first law, their body mass wants to remain where it was, therefore they feel "thrown backward" when the bus speeds up. Mr. N then asks what students felt when going around the circle. They responded that they felt "thrown toward the outside of the circle." The teacher explains that this is their mass tending to go in a straight line and introduces the concept of centripetal force.

Mr. N challenges his students by telling them that at the instant when the bus was stopped — going neither forward or backward — the acceleration did not stop. He asks, "What will happen to acceleration at the top of the rise, if I threw a ball upward?" Most students answer "Zero." He reminds them of what they saw happening to the balloon on the bus. The idea that velocity can be zero when the acceleration is not zero is not easy for them to accept or to understand, but since they experienced it on the bus, the students cannot deny it.

Finally, the students calibrate the activity. Students measure the amount of acceleration by using the bus speedometer and a stopwatch to make a scale of degree of slant as a function of acceleration. Mr. N assesses students' understanding by asking students to identify different motions of a hypothetical bus, given several diagrams of balloon positions in that bus.

National Science Education Content Standards

9-12 Content Standard B

Structure of Atoms

- Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. The electric force between the nucleus and electrons holds the atom together.
- The atom's nucleus is composed of protons and neutrons, which are much more massive than electrons. When an element has atoms that differ in the number of neutrons, these atoms are called different isotopes of the element.
- The nuclear forces that hold the nucleus of an atom together, at nuclear distances, are usually stronger than the electric forces that would make it fly apart. Nuclear reactions convert a fraction of the mass of interacting particles into energy, and they can release much greater amounts of energy than atomic interactions. Fission is the splitting of a large nucleus into smaller pieces. Fusion is the joining of two nuclei at extremely high temperature and pressure, and is the process responsible for the energy of the sun and other stars.
- Radioactive isotopes are unstable and undergo spontaneous nuclear reactions, emitting particles and/or wavelike radiation. The decay of any one nucleus cannot be predicted, but a large group of identical nuclei decay at a predictable rate. This predictability can be used to estimate the age of materials that contain radioactive isotopes.

Structure and Properties of Matter

- Atoms interact with one another by transferring or sharing electrons that are furthest from the nucleus. These outer electrons govern the chemical properties of the element.
- An element is composed of a single type of atom. When elements are listed in order according to the number of protons (called the atomic number), repeating patterns of physical and chemical properties identify families of elements with similar properties. This "Periodic Table" is a consequence of the repeating pattern of outermost electrons and their permitted energies.
- Bonds between atoms are created when electrons are paired up by being transferred or shared. A substance composed of a single kind of atom is called an element. The atoms may be bonded together into molecules or crystalline solids. A compound is formed when two or more kinds of atoms bind together chemically.
- The physical properties of compounds reflect the nature of the interactions among its molecules. These interactions are determined by the structure of the molecule, including the constituent atoms and the distances and angles between them.
- Solids, liquids, and gases differ in the distances and angles between molecules or atoms and therefore the energy that binds them together. In solids the structure is nearly rigid; in liquids molecules or atoms move around each other but do not move apart; and in gases molecules or atoms move almost independently of each other and are mostly far apart.
- Carbon atoms can bond to one another in chains, rings, and branching networks to form a variety of structures, including synthetic polymers, oils, and the large molecules essential to life.

National Science Education Content Standards

9-12 Content Standard B (continued)

Chemical Reactions

- Chemical reactions occur all around us, for example in health care, cooking, cosmetics, and automobiles. Complex chemical reactions involving carbon-based molecules take place constantly in every cell in our bodies.
- Chemical reactions may release or consume energy. Some reactions, such as the burning of fossil fuels, release large amounts of energy by losing heat and by emitting light. Light can initiate many chemical reactions, such as photosynthesis and the evolution of urban smog.
- A large number of important reactions involve the transfer of either electrons (oxidation/reduction reactions) or hydrogen ions (acid/base reactions) between reacting ions, molecules, or atoms. In other reactions, chemical bonds are broken by heat or light to form very reactive radicals with electrons ready to form new bonds. Radical reactions control many processes such as the presence of ozone and greenhouse gases in the atmosphere, burning and processing of fossil fuels, the formation of polymers, and explosions.
- Chemical reactions can take place in time periods ranging from the few femtoseconds (10^{-15} seconds) required for an atom to move a fraction of a chemical bond distance to geologic time scales of billions of years. Reaction rates depend on how often the reacting atoms and molecules encounter one another, on the temperature, and on the properties—including shape—of the reacting species.
- Catalysts, such as metal surfaces, accelerate chemical reactions. Chemical reactions in living systems are catalyzed by protein molecules called enzymes.

Motion and Forces

- Objects change their motion only when a net force is applied. Laws of motion are used to calculate precisely the effects of forces on the motion of objects. The magnitude of the change in motion can be calculated using the relationship $F = ma$, which is independent of the nature of the force. Whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object.
- Gravitation is a universal force that each mass exerts on any other mass. The strength of the gravitational attractive force between two masses is proportional to the masses and inversely proportional to the square of the distance between them.
- The electric force is a universal force that exists between any two charged objects. Opposite charges attract while like charges repel. The strength of the force is proportional to the charges, and, as with gravitation, inversely proportional to the square of the distance between them.
- Between any two charged particles, electric force is vastly greater than the gravitational force. Most observable forces, such as those exerted by a coiled spring or friction, may be traced to electric forces acting between atoms and molecules.
- Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces. These effects help students to understand electric motors and generators.

National Science Education Content Standards

9-12 Content Standard B (continued)

Conservation of Energy and the Increase in Disorder	• The total energy of the universe is constant. Energy can be transferred by collisions in chemical and nuclear reactions, by light waves and other radiations, and in many other ways. However, it can never be destroyed. As these transfers occur, the matter involved becomes steadily less ordered. • All energy can be considered to be either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves. • Heat consists of random motion and the vibrations of atoms, molecules, and ions. The higher the temperature, the greater the atomic or molecular motion. • Everything tends to become less organized and less orderly over time. Thus, in all energy transfers, the overall effect is that the energy is spread out uniformly. Examples are the transfer of energy from hotter to cooler objects by conduction, radiation, or convection and the warming of our surroundings when we burn fuels.
Interactions of Energy and Matter	• Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter. • Electromagnetic waves result when a charged object is accelerated or decelerated. Electromagnetic waves include radio waves (the longest wavelength), microwaves, infrared radiation (radiant heat), visible light, ultraviolet radiation, x-rays, and gamma rays. The energy of electromagnetic waves is carried in packets whose magnitude is inversely proportional to the wavelength. • Each kind of atom or molecule can gain or lose energy only in particular discrete amounts and thus can absorb and emit light only at wavelengths corresponding to these amounts. These wavelengths can be used to identify the substance. • In some materials, such as metals, electrons flow easily, whereas in insulating materials such as glass they can hardly flow at all. Semiconducting materials have intermediate behavior. At low temperatures some materials become superconductors and offer no resistance to the flow of electrons.

Minnesota Graduation Standards

High School Level

Concepts in Chemistry:

Understand concepts, theories and principles in chemistry through investigation and analysis.

What students should know:

1. Understand atomic theory (e.g., isotopes, quantum theory)
2. Understand relationships between the structure and properties of matter:
   a. organic and inorganic bonding
   b. periodicity
   c. solutions chemistry
3. Understand chemical reactions (e.g., rates, stoichiometry)
4. Understand interactions of energy and matter (e.g., phase change, equilibrium)
5. Understand the historical significance of major scientific advances (e.g., periodic table, atomic theory)

What students should do:

1. Design and conduct an experiment to investigate a question and test a hypothesis in chemistry
2. Design and conduct one investigation through a problem-based study, service learning project or field study:
   a. identify scientific issues based on observations and the corresponding scientific concepts
   b. analyze data to clarify scientific issues or define scientific questions
   c. compare results to current models and/or personal experience
3. Use scientific evidence to defend or refute an idea in an historical or contemporary context:
   a. identify scientific concepts found in evidence
   b. evaluate the validity of the idea in relationship to scientific information
   c. analyze the immediate and long-term impact on the individual and/or society in the areas of technology, economics and the environment

In Addition:

1. Students are encouraged to communicate to an audience outside of the school setting whenever possible.
2. Students must demonstrate basic safety procedures and skills when using tools and equipment.

Minnesota Graduation Standards

High School Level (continued)

Concepts in Physics:

Understand physics through interactions of matter, force, and energy.

What students should know:

1. Understand the concept of motion (e.g., linear, circular, projectile)
2. Understand the concept of force (e.g., gravitational, electromagnetic, nuclear)
3. Understand laws of conservation (e.g., mass, momentum)
4. Understand concepts of electricity and magnetism (e.g., circuits, semi-conductors, super-conductors)
5. Understand the concepts of waves (e.g., sound, electromagnetic, geometric optics)
6. Understand concepts of energy and work (e.g., thermal, potential/kinetic, thermonuclear)
7. Understand the historical significance of major scientific advances (e.g., Newtonian mechanics, nuclear physics)

What students should do:

1. Design and conduct an experiment to investigate a question and test a hypothesis in physics
2. Analyze data to support or refute hypotheses
3. Design and conduct one investigation through a problem-based study, service learning project or field study
   a. identify scientific issues based on observations and the corresponding scientific concepts
   b. analyze data to clarify scientific issues or define scientific questions
   c. compare results to current models and/or personal experience
4. Use scientific evidence to defend or refute an idea in a historical or contemporary context:
   a. identify scientific concepts found in evidence
   b. evaluate the validity of the idea in relationship to scientific information
   c. analyze the immediate and long-term impact on the individual and/or society in the areas of technology, economics and the environment

In Addition:

1. Students are encouraged to communicate to an audience outside of the school setting whenever possible.
2. Students must demonstrate basic safety procedures and skills when using tools and equipment.