8710.4750 TEACHERS OF SCIENCE.

Subpart 1. **Scope of practice.** A teacher of chemistry, earth and space science, life science, or physics is authorized to provide instruction in all science disciplines to students in grades 5 through 8 and either chemistry, earth and space science, life science, or physics, and integrated science offerings, to students in grades 9 through 12. The science discipline that the teacher is qualified to teach in grades 9 through 12 shall be identified on the teacher's license.

Subp. 2. **Licensure requirements.** A candidate for licensure to teach science to students in grades 5 through 12 shall:

A. hold a baccalaureate degree from a college or university that is accredited by the regional association for the accreditation of colleges and secondary schools;

B. demonstrate the standards for effective practice for licensing of beginning teachers in part 8700.2000; and

C. show verification of completing a preparation program approved under part 8700.7600 leading to the licensure of teachers of science in grades 5 through 8 in subpart 3 and chemistry, earth and space science, life science, or physics in grades 9 through 12 in subpart 4, 5, 6, or 7.

Subp. 2a. **Exception for candidates with partial science teaching qualification.** The board shall issue a license valid for teaching chemistry, earth and space science, life science, or physics in grades 9 through 12 for candidates who complete the requirements of subpart 2, items A and B; and subpart 4; 5; 6; or 7, but have not completed subpart 3. The board shall issue a license to teach all sciences in grades 5 through 8 to a candidate who has completed the requirements of subparts 2, items A and B, and 3 but has not completed subpart 4, 5, 6, or 7. Licenses issued to teach all sciences in grades 5 through 8 under this exception or as a science specialty under part 8710.3200 are not valid for teaching integrated science offerings above grade 9.

Subp. 3. **Subject matter standards for science in grades 5 through 8.** A candidate for licensure as a teacher of science in grades 5 through 8 must complete a preparation program under subpart 2, item C, that must include the candidate's demonstration of the knowledge and skills in items A to F.

A. A teacher of science must demonstrate science perspectives, including:

(1) understanding and conducting science inquiry as evidenced by the ability to:

(a) ask appropriate theoretical or empirical questions about a given system or event that build on current scientific knowledge and can be answered scientifically;

(b) design and conduct, using appropriate methods, technology, and mathematical tools, a scientific investigation to answer a given question;

(c) develop, using appropriate sources of information, qualitative and quantitative solutions to problems;

(d) communicate clearly and concisely, using words, diagrams, tables, graphs, and mathematical relationships, the methods and procedures, results, and conclusions for a given empirical question or problem;

(e) justify a scientific explanation of a given system or event, compared to alternative explanations, based on the available empirical evidence, current scientific understanding, and logical arguments; and

(f) criticize, using knowledge of common errors of evidence and logic, a given science-related claim or argument; and

(2) understanding the history and nature of scientific knowledge as evidenced by the ability to:

(a) describe the evolution of scientific knowledge in a given historical context in terms of the contributions of male and female individuals from various cultures; the influence of society, culture, and personal beliefs of the scientists involved; and the accumulating empirical evidence and logical arguments used to develop the new knowledge;

(b) explain why scientists disagree on a given contemporary controversy in terms of the different assumptions made by the scientists, the different values the scientists place on a particular piece of evidence, and the limitations of the available data or theories, or both; and

(c) explain, using knowledge of the role of empirical evidence and logical argument in science and the assumption that the universe is a vast single system in which the basic rules are everywhere the same, why a given contemporary or historical belief is nonscience.

B. A teacher of science must have the knowledge and ability to make conceptual connections within and across the domains of science and between science and technology. The teacher of science must understand:

(1) connections across the domains of science as evidenced by the ability to:

(a) describe, using words and diagrams, a given technological, biological, physical, earth, or space system in terms of its components, inputs, outputs, and control or feedback;

(b) describe, using a specific example, the use of a given unifying theme or principle in the physical sciences, life sciences, and earth and space sciences; and

(c) explain, using unifying scientific principles, a given set of seemingly unrelated systems or events, both within a science domain and across science domains;

(2) connections between science and technology as evidenced by the ability to:

(a) describe the similarities and differences between the goals and processes of scientific inquiry and the goals and processes of technological design;

(b) explain how the availability of new technology influenced the development of scientific knowledge in a given contemporary or historical context and how the development of new scientific knowledge led to technological advances in a given contemporary or historical context;

(c) explain and predict the possible unexpected benefits and the negative side effects and unintended consequences of a given technological advance;

(d) explain why the contributions of individuals from different scientific disciplines and of technology were necessary for the success of a given contemporary or historical scientific investigation; and

(e) design a modification or use of a system to meet certain needs or criteria in either chemistry, earth and space science, biology, or physics; and

(3) connections between science and other school subjects as evidenced by the ability to:

(a) communicate clearly and precisely, using words, physical models, computer models, demonstrations, diagrams, flow charts, numbers, tables, graphs, and appropriate mathematical relationships, the observations, methods and procedures, results, and conclusions for a given empirical question or problem; explanations of how or why something happens; predictions of what will happen when a change is made; the design for modifying or using a system; and the evaluation of the design against the needs or criteria it was designed to meet;

(b) interpret a given text, physical or computer model, demonstration, diagram, flow chart, set of numbers, table, graph, and appropriate mathematical relationships;

(c) use computer software or graphing calculators to display and analyze data and to model solutions to a prediction or design problem;

(d) explain how mathematics influenced the development of scientific knowledge in a given contemporary or historical context, and how the development of new

scientific knowledge led to new mathematics in a given contemporary or historical context; and

(e) describe the impact on society and culture of a given historical development of scientific ideas.

C. A teacher of science understands how knowledge of concepts and principles of science and technology and knowledge of factors influencing personal and community health, population growth, natural resources, environmental quality, and natural and human-induced hazards influence decisions about personal and societal issues. The teacher of science must:

(1) predict the scientific, economic, political, and ethical factors that could influence a course of action to address a given personal issue or local, national, or global challenge;

(2) design, using the systematic approaches of science and scientific knowledge, a course of action to address a personal issue or a given local, national, or global challenge; and

(3) justify and defend a given design for a course of action in terms of an assessment of alternatives, risks, costs, and benefits, and consideration of who benefits and who suffers, who pays and gains, and what the risks are and who bears them.

D. A teacher of science must be able to understand and apply fundamental principles, laws, and concepts of earth and space science, life science, and physical science. The teacher of science must:

(1) know and apply the fundamental principles, laws, and concepts of earth and space science including understanding:

(a) the components and evolution of the Earth system as evidenced by the ability to:

i. describe, using words, diagrams, pictures, and graphs, the physical properties of a given Earth material;

ii. explain, from observation of its composition, texture, and physical state using physical, geological, or biological processes, a plausible way in which a given rock formed through time;

iii. explain, in terms of environmental changes, structural events, plate tectonics, and sedimentary, igneous, metamorphic, and biologic processes, how observed differences within a given rock sequence are related to the various processes that may have formed the rocks;

iv. explain, in terms of environmental changes, structural events, plate tectonics, and sedimentary, igneous, metamorphic, and biologic processes, a plausible way in which a given rock sequence formed through time;

v. explain, in terms of the physical processes that formed it, the origin and development of a given Earth structure;

vi. predict, in terms of known rock sequences, how a given geologic or biologic event might be recorded in a rock sequence; and

vii. explain, using the fossil record and decay rates of radioactive isotopes, how the age of a given rock is determined;

(b) matter and energy in the Earth system as evidenced by the ability to:

i. explain, using convection, conduction, and radiation, how matter is transported and how energy drives the process of transportation of matter within and between given Earth subsystems or structures;

ii. explain, using convection, conduction, radiation, and conservation of energy, how energy is transmitted and transformed within and between given Earth subsystems or structures;

iii. design a simple physical model that mimics the behavior of a given Earth system; and

iv. describe, using words, diagrams, and chemical equations, the processes involved in the movement of chemical elements or compounds among different given chemical reservoirs in the Earth;

(c) the Earth in the solar system and the universe as evidenced by the ability to:

i. explain how the properties and organization of galaxies provide evidence that the universe is continuously changing;

ii. explain qualitatively, using fundamental processes of chemical, physical, and geological change, how processes of change on a given solar system object are different or similar to Earth;

iii. describe, using words, diagrams, and physical models, the motion of objects in our solar system; and

iv. explain qualitatively, using Earth's axial rotation, tilt of its rotational axis, and changing position with respect to the sun, the seasonal variations in the length of a day and sun angle at various latitudes on Earth; and

(d) human interactions with the earth system as evidenced by the ability to:

i. describe, using words, diagrams, pictures, graphs, historic records, and physical models, the scientific basis for predicting the occurrence of a given environmental hazard on a human time frame;

ii. describe, using words, diagrams, pictures, maps, and physical or computer models, the observed changes in a given Earth system that are due directly or indirectly to human activity; and

iii. predict, using words, diagrams, pictures, maps, and physical or computer models, the probable movement of pollutants in a given Earth system;

(2) know and apply the fundamental principles, laws, and concepts of life science including understanding:

(a) structural and functional relationships in living systems and environments as evidenced by the ability to:

i. perform observations to describe the macroscopic structures of a given common organism;

ii. describe, using words, pictures, and diagrams, the conditions required to sustain life for a given common organism;

iii. describe, using words and diagrams, the characteristics of what determines life in a given common organism;

iv. design a system to support, sustain, and continue the life of a given set of common organisms;

v. describe, using words, pictures, dioramas, and physical or computer models, the structure and function of the components of a given living system in relation to its overall function;

vi. explain, in terms of the function of the organs of that system, the structure of a given plant and animal system;

vii. explain, using structure-function relationships, how and why the structures for a given function are different in different given species;

viii. describe the origins, transmission, prevention, management, or cure of a given disease; and

ix. explain and predict, in terms of the defense mechanism and the method by which the immunity is established, how a given active or passive immunity functions in a human;

(b) molecular and cellular life processes as evidenced by the ability to:

i. perform observations to describe cellular structures and physiological processes;

ii. describe, using words, pictures, and models, the components of a given cell;

iii. explain, in terms of the structure and function of the cell components, the differences between prokaryotic and eukaryotic cells and between given eukaryotic cells;

iv. describe, using words, pictures, and diagrams, the cellular processes of a given plant or animal cell;

v. explain, using the process of photosynthesis, how plants transform solar energy into cellular energy;

vi. explain, using the process of cellular respiration, how energy stored in food molecules is released;

vii. explain, using the process of DNA replication, how proteins are synthesized in a cell;

viii. explain, using the structure-function relationships between cells, tissues, organs, and systems, how cells function as primary building blocks of an organism;

ix. describe, using words, pictures, and models, the physical changes at each given stage of cellular asexual reproduction;

x. describe, using words, diagrams, and charts, how traits are inherited and sex is determined in a given animal; and

xi. explain, using the relationships between genetic change and expression, how a mutation occurs and predict the effect an environmental change will have on the expression of a trait;

(c) diversity and biological evolution as evidenced by the ability to:

i. describe, using words, pictures, and diagrams, the range of physical and behavioral adaptations that can occur in response to environmental stresses for a given species;

ii. describe, using words, diagrams, charts, and graphs, the range of observable characteristics of a given species in a given environment;

iii. explain the speciation process in a given fossil record; and

iv. design, based only on observable structure, a classification key for a given set of organisms; and

(d) the interdependence among living things as evidenced by the ability to:

i. collect and analyze data to describe the diversity and number of species in a given ecosystem;

ii. describe, using words, pictures, and diagrams, the biotic and abiotic components of a given niche, habitat, ecosystem, or biome;

iii. explain, in terms of environmental adaptations and development, the diversity of a given species;

iv. describe, using words and diagrams, the cycling of matter and the flow of energy within a given system;

v. explain and predict the behavioral responses of an animal to a given set of environmental changes; and

vi. design, using environmental changes, an experiment to elicit a specific behavioral response from a given animal; and

(3) know and apply the fundamental principles, laws, and concepts of the physical sciences including understanding:

(a) one-dimensional and two-dimensional linear motion and forces as evidenced by the ability to:

i. perform measurements and calculations to determine the position, average speed, and direction of motion of a given object;

ii. describe, using words, pictures or diagrams, graphs, vectors, and simple mathematical relationships, the vertical and horizontal components of the motion of a given object;

iii. describe, using words and free body vector diagrams, the forces acting on an object in a given system of interacting objects, and explain qualitatively, using Newton's Second and Third Laws, the relationships between all the forces;

iv. describe, using words, energy diagrams or graphs, and simple mathematical relationships, the change of energy of a system and any transfer of energy into or out of a given system of interacting objects; and

v. explain qualitatively, in terms of balanced and unbalanced forces and the conservation of energy, the observed motion of an object in a given system of interacting objects;

(b) vibrations and wave motion as evidenced by the ability to:

i. perform measurements and calculations to describe the wavelength, amplitude, period, and frequency of a given oscillating object or wave;

ii. describe, using words, diagrams, and graphs, the frequency and amplitude of a given simple pendulum or vibrating object;

iii. describe, using words, diagrams, and graphs, the wave motion of a traveling or standing wave in a given medium; and

iv. explain qualitatively, in terms of the changes in the frequency amplitude, wavelength, or wave velocity, the observed changes in the pitch or intensity of a sound when given changes are made to the source, the medium through which the sound travels, or the relative motion of the source or detector;

(c) the behavior of light as evidenced by the ability to:

i. explain qualitatively, using the directionality and chromatic composition of light, how we see a given object and its color;

ii. explain and predict, using ray diagrams, the observed shadows in a simple geometrical system of objects and point or extended light sources;

iii. describe, using words and ray diagrams, the reflection, refraction, transmission, and absorption of light when it encounters an ordinary object, a plain or curved mirror, a prism, and thin concave or convex lenses; and

iv. explain qualitatively, using ray diagrams and the laws of reflection and refraction of light, the observed location and magnification of the real or virtual images for a given pinhole system, simple system of mirrors, or simple system of thin lenses;

(d) electricity and magnetism as evidenced by the ability to:

i. perform measurements to determine the type of charge of a given charged object, and the north and south poles of an unmarked magnet;

ii. explain qualitatively, in terms of the movement of electrons, observed changes in the charge of an object in a given system of interacting charged and uncharged objects;

iii. describe, using words and diagrams, the magnetic field around a straight current carrying wire and a current-carrying solenoid; and

iv. design a circuit using batteries, bulbs, and switches to meet given criteria for the brightness and control of the bulbs;

(e) the properties and structure of matter as evidenced by the ability to:

i. perform measurements and calculations to describe the mass, volume, density, concentration, melting and boiling temperatures, and solubility limits of a given substance;

ii. describe, using words and diagrams, common substances as pure elements or compounds, solutions, suspensions, or colloids;

iii. perform procedures of distillation, precipitation, extraction, or chromatography to separate the substances in a given mixture;

iv. describe, using words and diagrams, the basic atomic and subatomic constituents of matter;

v. describe, using the kinetic-molecular theory or intermolecular forces, or both, the arrangement and motion of the atoms, ions, or molecules in a given gas, liquid, or solid substance, and explain the characteristic properties of the substance;

vi. explain and predict, using the principles for filling the electron orbital of atoms and the Periodic Table, the periodic trends in electrical conductivity, ionization, and metallic character of a given set of elements;

vii. predict, using the Periodic Table, whether the bonding in a given substance is primarily covalent, metallic, or ionic;

viii. describe, with words and diagrams, the electrical conductivity of a given conductor, insulator, or semiconductor using periodic trends;

ix. describe, in words and diagrams using conservation of mass and energy, the changes in matter and energy that occur in the nuclear processes of radioactive decay, fission, and fusion; and

x. describe, with words, structural and chemical diagrams and formulas, and physical and computer models, the unique structure of carbon, and explain how that structure results in the large variety of organic molecules;

(f) chemical reactions as evidenced by the ability to:

i. describe, using words, diagrams, physical or computer models, and a balanced chemical equation, changes in the energy and arrangement of atoms for a given chemical reaction;

ii. describe, using words, diagrams, and chemical symbols, a given chemical reaction as oxidation-reduction, acid-base, free radical, precipitation, metathesis, or a combination of these; and

iii. explain and predict qualitatively, using solubility rules, the common oxidation states of elements, the activity series of metals and nonmetals, the

stability of radicals, and the properties of acids and bases, the most likely type of reaction for a given set of given reactants;

(g) thermodynamics as evidenced by the ability to:

i. describe, using words and pictures or diagrams, the characteristics of an ideal gas;

ii. describe and predict, using words, graphs, and mathematical relationships, changes in pressure, volume, or temperature of a given ideal gas;

iii. describe, using words, diagrams, and energy graphs, the changes in the enthalpy and entropy during a given chemical reaction; and

iv. explain qualitatively, using the First and Second Laws of Thermodynamics energy, changes in a given spontaneous or nonspontaneous reaction; and

(h) chemical kinetics and equilibrium as evidenced by the ability to:

i. explain, using the requirements for effective particle collisions and activation energy, why a given spontaneous reaction is fast or slow, and predict the conditions necessary to make the reaction occur more rapidly;

ii. explain, using the concept of activation energy and the requirements for effective particle collisions, how a given catalyst increases the rate of a given reaction;

iii. explain, using the kinetic-molecular model, how a given change in temperature, concentration, or particle surface area changes the rate of a given chemical reaction;

iv. describe, using words, diagrams, chemical equations, and concentration graphs, the equilibrium of a given reaction;

v. explain, in terms of changes in the number of effective collisions of the molecules in the forward and reverse reaction, why the chemical equilibrium of a given reaction is a dynamic process; and

vi. explain and predict change in the equilibrium of a given chemical reaction when the temperature changes, the pressure changes, a catalyst is added, or the concentration of reactants or products changes.

E. A teacher of science must have a broad-based knowledge of teaching science that integrates knowledge of science with knowledge of pedagogy, students, learning environments, and professional development. A teacher of science must understand:

(1) curriculum and instruction in science as evidence by the ability to:

(a) select, using local, state, and national science standards, appropriate science learning goals and content;

(b) plan a coordinated sequence of lessons and instructional strategies that support the development of students' understanding and nurture a community of science learners including appropriate inquiry into authentic questions generated from students' experiences; strategies for eliciting students' alternative ideas; strategies to help students' understanding of scientific concepts and theories; and strategies to help students use their scientific knowledge to describe real-world objects, systems, or events;

(c) plan assessments to monitor and evaluate learning of science concepts and methods of scientific inquiry; and

(d) justify and defend, using knowledge of student learning, research in science education, and national science education standards, a given instructional model or curriculum;

(2) safe environments for learning science as evidenced by the ability to:

(a) use required safety equipment correctly in classroom, field, and laboratory settings;

(b) describe, using knowledge of ethics and state and national safety guidelines and restrictions, how to make and maintain a given collection of scientific specimens and data;

(c) describe, using knowledge of ethics and state and national safety guidelines and restrictions, how to acquire, care for, handle, and dispose of live organisms;

(d) describe, using state and national guidelines, how to acquire, care for, store, use, and dispose of given chemicals and equipment used to teach science;

(e) implement safe procedures during supervised science learning experiences in the public schools; and

(f) develop a list of materials needed in an elementary science safety kit;

(3) how to apply educational principles relevant to the physical, social, emotional, moral, and cognitive development of preadolescents and adolescents;

(4) how to apply the research base for and the best practices of middle level and high school education;

(5) how to develop curriculum goals and purposes based on the central concepts of science and how to apply instructional strategies and materials for achieving student understanding of the discipline;

(6) the role and alignment of district, school, and department mission and goals in program planning;

(7) the need for and how to connect students' schooling experiences with everyday life, the workplace, and further educational opportunities;

(8) how to involve representatives of business, industry, and community organizations as active partners in creating educational opportunities;

(9) the role and purpose of cocurricular and extracurricular activities in the teaching and learning process; and

(10) how to apply the standards of effective practice in teaching through a variety of early and ongoing clinical experiences with middle level and high school students within a range of educational programming models.

F. A teacher of science must understand the content and methods for teaching reading including:

(1) knowledge of reading processes and instruction including:

(a) orthographic knowledge and morphological relationships within words;

(b) the relationship between word recognition and vocabulary knowledge, fluency, and comprehension in understanding text and content materials;

(c) the importance of direct and indirect vocabulary instruction that leads to enhanced general and domain-specific word knowledge;

(d) the relationships between and among comprehension processes related to print processing abilities, motivation, reader's interest, background knowledge, cognitive abilities, knowledge of academic discourse, and print and digital text; and

(e) the development of academic language and its impact on learning and school success; and

(2) the ability to use a wide range of instructional practices, approaches, methods, and curriculum materials to support reading instruction including:

(a) the appropriate applications of a variety of instructional frameworks that are effective in meeting the needs of readers of varying proficiency levels and linguistic backgrounds in secondary settings;

(b) the ability to scaffold instruction for students who experience comprehension difficulties;

(c) selection and implementation of a wide variety of before, during, and after reading comprehension strategies that develop reading and metacognitive abilities;

(d) the ability to develop and implement effective vocabulary strategies that help students understand words including domain-specific content words;

(e) the ability to develop critical literacy skills by encouraging students to question texts and analyze texts from multiple viewpoints or perspectives;

(f) the ability to identify instructional practices, approaches and methods and match materials, print and digital, to the cognitive levels of all readers, guided by an evidence-based rationale, which support the developmental, cultural, and linguistic differences of readers;

(g) the ability to plan instruction and select strategies that help students read and understand science texts, including the ability to:

i. distinguish between facts based on empirical/scientific findings from opinion;

ii. relate what is read to relevant prior knowledge;

iii. use scientific knowledge to draw inferences or conclusions from facts, discern cause and effect relationships, detect fallacies in author's evidence, and support own claims with evidence;

iv. follow instructions to perform laboratory activities step by step in a disciplined fashion;

v. explain diagrams and graphs in terms of scientific content/meaning; and

vi. explain meaning of abbreviations and symbols.

Subp. 4. **Subject matter standards for teachers of chemistry.** A candidate for licensure as a teacher of chemistry in grades 9 through 12 must complete a preparation

program under subpart 2, item C, that must include the candidate's demonstration of the knowledge and skills in items A to C, and subpart 3, items E and F.

A. A teacher of chemistry must demonstrate a conceptual understanding of chemistry. The teacher must:

(1) use sources of information to solve unfamiliar quantitative problems and communicate the solution in a logical and organized manner as evidenced by the ability to:

(a) describe, in terms of the known and unknown quantities, a given problem in appropriate pictorial, graphical, or written forms;

(b) describe, in terms of the relevant numerical and algebraic quantities and equations, a given problem mathematically;

(c) plan, using words, diagrams, and mathematical relationships, a solution for a given problem in terms of steps necessary to solve the problem and to verify the solution; and

(d) evaluate, in terms of unit consistency, reasonableness, and completeness of solution, the solution of a given problem;

(2) use computers to display and analyze experimental and theoretical data as evidenced by the ability to:

(a) describe data graphically using a computer; and

(b) design a mathematical model to provide a reasonable fit to a given set of data; and

(3) develop a plan to ensure a safe environment and practices in chemistry learning activities.

B. A teacher of chemistry must demonstrate a knowledge of chemistry concepts. The teacher must:

(1) understand the properties and structure of matter as evidenced by the ability to:

(a) explain and predict, using the principles for filling the electron orbitals of atoms and the Periodic Table, the periodic trends in electrical conductivity, atomic radii, ionization energy, electronegativity, electron affinity, and metallic character of a given set of elements;

(b) predict, using the Periodic Table and the arrangement and energies of the element's outermost electrons, whether the bonding in a given substance is primarily covalent, metallic, or ionic;

(c) explain and predict, using the periodic trends in the physical and chemical characteristics of the elements and the type of bonds, or intermolecular forces, or both, the relative magnitudes of a given property for a set of elements or compounds;

(d) predict, using existing models including the Valence Shell electron Pair Repulsion theory, the shape of a given molecule; and

(e) describe, with words and diagrams using neutron to proton ratios and binding energies, the changes in matter and energy that occur in the nuclear processes of radioactive decay, fission, fusion, and other common nuclear transformations;

(2) understand chemical reactions as evidenced by the ability to:

(a) perform measurements and calculations to determine the chemical formulas of the products of a given chemical reaction;

(b) explain and predict qualitatively and quantitatively, using the Periodic Table and the concept of chemical stoichiometry, the mass relationships between reactants and products for a given chemical reaction;

(c) predict quantitatively, using the principle of state functions and Hess's Law, the molar heat of a given reaction from known values of molar heats of formation or molar heats of a series of related reactions; and

(d) explain and predict qualitatively and quantitatively, using solubility rules, the common oxidation states of elements, the activity series of metals and nonmetals, stability of radicals, and the properties of acids and bases, the most likely type of reaction for a given set of given reactants;

(3) understand thermodynamics as evidenced by the ability to:

(a) perform measurements and calculations to determine the molar heat energy absorbed or released in a given phase change or chemical reaction;

(b) predict qualitatively and quantitatively, using the Ideal Gas Law, changes in the pressure, volume, temperature, or quantity of gas in a given thermally isolated ideal gas system when the gas is heated or cooled, is compressed or expanded adiabatically, or enters or leaves the system;

(c) describe, using words, diagrams, energy graphs, and mathematical relationships, the changes in the enthalpy, entropy, and Gibb's free energy during a given chemical reaction;

(d) explain and predict qualitatively and quantitatively, using the First and Second Laws of Thermodynamics and the relationship between Gibb's free energy and the equilibrium constant, changes in the equilibrium and Gibb's free energy for a given change in the reaction conditions;

(e) design, using Gibb's free energy, a method for changing the direction of spontaneity of a given reaction; and

(f) explain qualitatively and quantitatively, using Gibb's free energy, how the electrochemical potential of a given cell depends on given changes in the temperature or the concentration of ions in solution, or both;

(4) understand chemical kinetics and equilibrium as evidenced by the ability to:

(a) perform measurements and calculations to determine the rate of a chemical reaction, the rate expression, half-life of given reaction, the activation energy of a given reaction, and the equilibrium constant of a given reaction;

(b) describe, using words, energy diagrams, graphs, and mathematical relationships, the activation energy, enthalpy changes, and reaction rate of a given reaction;

(c) explain and predict qualitatively and quantitatively, using the rate equation for the reaction, changes in the reaction rate for a given change in the concentration of a reactant or product;

(d) predict, using the rate equation and the presence or absence of intermediates, a possible mechanism for a given reaction;

(e) describe, using words, diagrams, chemical equations, concentration and rate graphs, and mathematical relationships, the equilibrium of a given reaction;

(f) explain, in terms of changes in the number of effective collisions of the molecules in the forward and reverse reaction, why the chemical equilibrium of a given reaction is a dynamic process;

(g) explain and predict quantitatively, using the equilibrium constant, the concentration of a reactant or product in a given gas phase or solution chemical reaction;

(h) design, using LeChatelier's principle, a method for achieving a specified change in the equilibrium constant or the position of equilibrium of a given chemical reaction; and

(i) design, using the rate laws and requirements for effective collisions, a method for achieving a specified change in the rate of a given chemical reaction; and

(5) understand organic and biochemical reactions as evidenced by the ability to:

(a) perform measurements and calculations to determine the melting point, boiling point, solubility, or other common physical properties of an organic compound;

(b) describe, using words, structural and chemical formulas, and physical and computer models, the functional groups and polarity of the molecule of a given organic compound;

(c) describe, using words, structural and chemical formulas, and physical or computer models, a given hydrocarbon compound as aromatic or aliphatic; saturated or unsaturated; alkanes, alkenes, or alkynes; and branched or straight chains;

(d) explain and predict, using a molecular orbital model of the pi-bond, the outcomes of reactions of given aromatic, allylic and conjugated alkenes, and other delocalized electron systems;

(e) explain and predict, using functional groups, structure, and polarity, the reactivity, solubility, melting point, and boiling point of an organic compound;

(f) predict, using infrared, nuclear magnetic resonance, and mass spectra, the structure of an organic molecule;

(g) design and carry out a single step synthesis of an organic compound, purify the compound, and characterize the product;

(h) describe, using words, diagrams, structural and chemical formulas, and physical and computer models, the origin of optical activity of a given chiral organic compound;

(i) explain why the reactivity of a chiral compound depends on its stereo chemistry when acted upon by a living system, and predict whether a particular substrate enantiomer would or would not react with its enzyme;

(j) describe, using words, structural and chemical formulas, and physical and computer models, a given set of biomolecules as a carbohydrate, lipid, protein, or nucleic acid, and explain how biomolecules are made from typical chemical components by chemical reactions;

(k) perform tests and measurements to determine if a given biological substance is a carbohydrate, lipid, protein, or nucleic acid;

(l) explain, using the concepts of electrostatic attraction, repulsion, and stereochemistry in the catalytic process, how enzymes facilitate a given biochemical reaction; and

(m) design a method to use organic compounds to demonstrate a given general chemical principle.

C. A teacher of chemistry must demonstrate an advanced conceptual understanding of chemistry and the ability to apply its fundamental principles, laws, and concepts by completing a full research experience. The teacher must:

(1) identify various options for a research experience including independent study projects, participation in research with an academic or industry scientist, directed study, internship, or field study;

(2) select an option and complete a research experience that includes conducting a literature search on a problem;

(3) design and carry out an investigation;

(4) identify modes for presenting the research project; and

(5) present the research project in the selected mode.

Subp. 5. **Subject matter standards for teachers of earth and space science.** A candidate for licensure as a teacher of earth and space science in grades 9 through 12 must complete a preparation program under subpart 2, item C, that must include the candidate's demonstration of the knowledge and skills in items A to C, and subpart 3, items E and F.

A. A teacher of earth and space science must demonstrate a conceptual understanding of earth science. The teacher must:

(1) use sources of information to solve unfamiliar qualitative and quantitative problems and communicate the solution in a logical and organized manner as evidenced by the ability to:

(a) describe, in terms of the known and unknown quantities, a given problem in appropriate pictorial, graphical, or written forms;

(b) translate a given topographical or geological map into a cross-sectional view;

(c) describe qualitatively in appropriate terms, using words, stratigraphic columns, flow charts, maps, cross-sectional views, graphs, and drawings as necessary, a given problem situation;

(d) plan, using words, diagrams, pictures, and simple mathematical relationships, a solution for a given problem in terms of steps necessary to solve the problem and to verify the solution; and

(e) evaluate, in terms of unit consistency, reasonableness, and completeness of solution, the solution of a given problem;

(2) use computers to display and analyze experimental and theoretical data as evidenced by the ability to:

(a) describe data graphically using a computer; and

(b) design a mathematical model to provide a reasonable fit to a given set of data; and

(3) develop a plan to ensure a safe environment and practices in all earth and space science learning activities.

B. A teacher must demonstrate knowledge of earth and space science concepts. The teacher must:

(1) understand the components that make up the Earth system as evidenced by the ability to:

(a) perform measurements and statistical analyses to describe the physical properties of a given Earth material;

(b) explain for a given Earth material, in terms of chemical bond strength and chemical composition, how physical properties are related to basic chemical structure;

(c) describe, using words, pictures, diagrams, maps or globes, and satellite images, the component materials, large scale structures, and dominant physical processes of a given Earth subsystem; and

(d) explain, using seismic evidence, laboratory simulations of Earth-interior conditions, terrestrial and extraterrestrial samples, and models of chemical differentiation, how we know the interior of the Earth is segregated chemically and physically into layers;

(2) understand energy in the Earth system as evidenced by the ability to:

(a) describe, using words, pictures, diagrams, and physical or computer models, the radiant, chemical, nuclear, and gravitational energies of a given Earth subsystem or structure;

(b) describe, using words, pictures, diagrams, and physical or computer models, the flow of energy within and between given Earth subsystems or structures;

(c) describe, using words, pictures, diagrams, mathematical and chemical equations, physical or computer models, and electronic data sets, the transportation of matter within and between given Earth subsystems and structures; and

(d) explain and predict, in terms of conservation of energy, dynamic equilibrium, and geologic or atmospheric models, changes in behavior of an Earth subsystem or structure due to a given change in energy;

(3) understand geochemical cycling as evidenced by the ability to:

(a) explain, in terms of reaction equilibrium and disequilibrium and mass balance, how chemical elements and compounds in a given simple Earth system are distributed;

(b) explain and predict quantitatively and qualitatively, using related experimental data and the principles of mass balance and chemical equilibrium, how the concentration of an element or compound will change in a given reservoir interacting with another given reservoir;

(c) describe, using words, pictures, and diagrams, the concentration and depletion of given elements or compounds in a given reservoir; and

(d) explain, using mass balance, advection, convection, and chemical equilibrium, the process by which a given depletion or concentration of elements or compounds could have occurred in a given reservoir;

(4) understand the origin and evolution of the universe as evidenced by the ability to:

(a) describe, using words, drawings, and graphs, the properties of a given galaxy;

(b) explain, using the observed distribution of structural types, the relationship between astronomical distances and age, and the Big Bang theory, how differences in the composition and types of galaxies and the organization of galaxies into systems lead us to conclude that the universe is continuously changing;

(c) perform measurements to describe the spectral distribution of light from a given star;

(d) explain and predict, using the Hertzsprung-Russell Diagram, distance to the star, and stellar models, the changes in mass, luminosity, and size of a given star as it evolves from birth to death;

(e) explain, using models of stellar evolution, how stars die and become neutron stars and black holes;

(f) explain, using theories for nuclear stabilities and nuclear reactions, how elements can be formed in stars and novae;

(g) describe, using words, pictures, diagrams, and mathematical relationships, the distance over which a given astronomical distance scale is accurate; and

(h) explain, using blackbody radiation and quantization of energy levels, how to determine the temperature and elemental composition of a stellar object from its spectral signature;

(5) understand the Earth in the solar system as evidenced by the ability to:

(a) describe, with words, chemical formulas, drawings, scaled diagrams, and numerical orders of magnitude, the mass, size, and composition for a given solar system object;

(b) explain and predict, using geologic and climatic stability, availability of nutrients, and atmospheric parameters, the suitability for life for a given planetary description;

(c) explain and predict quantitatively and qualitatively, using Newton's laws of motions and gravitation and conservation of momentum, the motion of the bodies of a given solar system;

(d) explain, with words, diagrams, and models using orbital paths and relative sizes of solar system objects, the locationally dependent observation of solar and lunar eclipses and phases of the moon for a given simple solar system;

(e) explain, using Newton's laws of motion and gravitation and relative orbital positions, the origin of oceanic tides on the Earth; and

(f) design a physical solar-planetary model to demonstrate eclipses and lunar phases;

(6) understand the evolution of the Earth as evidenced by the ability to:

(a) perform measurements to describe the physical properties of a given rock sequence;

(b) describe, using words, pictures, and diagrams, the composition, textures, spatial relationships, and fossil content of a given rock sequence;

(c) explain, in terms of type and quantity of fossils, isotopic concentrations, unconformities, rock types, and rock sequences, the connection between a given major biospheric change and the rock and fossil record and a given major lithospheric change and the rock and fossil record;

(d) explain, using the principle of actualism, the relationship between features seen in the rock record and processes observable in the Earth today;

(e) predict, in terms of known rock sequences and the principle of actualism, how a given geologic or biologic event might be recorded in a rock sequence; and

(f) explain, using the fossil record and decay rates of radioactive isotopes, how the age of a given rock is determined; and

(7) understand human interactions with the Earth system as evidenced by the ability to:

(a) describe, using words, charts, figures, and maps or globes, the present distribution of a given natural resource;

(b) explain, using words, charts, figures, illustrations, and maps, how the distribution of a given resource has affected the distribution and history of human society;

(c) predict, in terms of present trends, possible alternative resources, and changes in technology or social structure, the plausible impacts on human society of future changes in the availability of a given natural resource;

(d) describe, using words, charts, figures, and maps or globes, a given occurrence of an environmental hazard;

(e) predict, in terms of direct and indirect, short-term and long-term effects, the probable impacts of a given environmental hazard on human society;

(f) explain, in terms of chemical changes, physical modifications, and changes in energy, how human activity impacts a given Earth system;

(g) predict, in terms of direct and indirect, short-term and long-term effects, the probable effects of a given human activity on an Earth system;

(h) explain, using words, diagrams, graphs, and maps, how it is known that there have been long-term changes in climate and sea level during the course of human existence;

(i) explain, using words, diagrams, pictures, and maps, how observed changes in climate and sea level may have impacted the history of human development; and

(j) predict, in terms of changes in resource availability, production, population size and distribution, and current social structures, the probable impacts of future changes in climate or sea level on human society.

C. A teacher of earth and space science must demonstrate an advanced conceptual understanding of earth and space science and the ability to apply its fundamental principles, laws, and concepts by completing a full research experience. The teacher must:

(1) identify various options for a research experience including independent study projects, participation in research with an academic or industry scientist, directed study, internship, or field study;

(2) select an option and complete a research experience that includes conducting a literature search on a problem;

(3) design and carry out an investigation;

(4) identify modes for presenting the research project; and

(5) present the research project in the selected mode.

Subp. 6. **Subject matter standards for teachers of life science.** A candidate for licensure as a teacher of life science in grades 9 through 12 must complete a preparation program under subpart 2, item C, that must include the candidate's demonstration of the knowledge and skills in items A to C, and subpart 3, items E and F.

A. A teacher of life science must demonstrate a conceptual understanding of life science. The teacher must:

(1) use sources of information to solve unfamiliar quantitative problems and communicate the solution in a logical and organized manner as evidenced by the ability to:

(a) describe, using appropriate alternative forms including pictorial, graphical, or written descriptions, the known and unknown quantities of a given problem; and

(b) describe, in terms of the relevant numerical and algebraic quantities and equations required to solve the problem, the relevant numerical and algebraic quantities and equations required to solve a given problem mathematically;

(2) use computers to display and analyze experimental and theoretical data as evidenced by the ability to:

(a) describe data graphically using a computer; and

(b) design a mathematical model to provide a reasonable fit to a given set of data;

(3) use mean, standard deviation, chi-squared, linear regression, and correlation to describe and analyze experimental and theoretical data; and

(4) develop a plan to ensure a safe environment and practices in all life science learning activities.

B. A teacher of life science must demonstrate knowledge of biological concepts. The teacher must:

(1) understand structural and functional relationships as evidenced by the ability to:

(a) perform observations to describe the structures of a given common organism;

(b) describe, using words, descriptions of appropriate experimental procedures, and diagrams, the characteristics of what determines life in a given common organism;

(c) predict, using structure-function relationships, the system function from which a given set of plant and animal tissue samples is derived;

(d) describe, using words, diagrams, and pictures, immune system responses that take place in human cells, tissues, organs, and organ systems throughout the progression of a given viral, bacterial, fungal, and parasitic disease; and

(e) design a personal course of action to prevent a given human disease;

(2) understand molecular and cellular life processes as evidenced by the ability to:

(a) perform measurements to describe cellular structures and physiological processes;

(b) describe, using words, chemical formulas and equations, and diagrams, the cellular processes of a given plant or animal cell;

(c) explain, using the structure-function relationship of the chloroplast, conservation of energy, and the fundamental nature of light, how solar energy is transformed during photosynthesis into cellular energy in a given plant cell;

(d) explain, using the structure-function relationship of the mitochondria and molecular energy transformations involving ATP, how energy stored in food molecules is released during cellular respiration in a given cell;

(e) qualitatively predict, using structure-function relationships and relationships between organelles and the cellular environment, the effect of a given natural and applied physical and chemical change in the environment of a cell on photosynthesis and cellular respiration;

(f) design experiments to test the properties of structure-function relationships in photosynthesis or cellular respiration;

(g) explain, using the processes of replication, transcription, and translation, how proteins are synthesized in a cell; and

(h) predict the amino acid sequence of a protein from a given codon sequence;

(3) understand molecular reproduction and heredity as evidenced by the ability to:

(a) perform measurements and statistical analyses to describe the results from a given plant and animal breeding experiment;

(b) describe, using words, pictures, and diagrams, and models, the changes in the visibility, arrangement, and number of chromosomes at each given state of mitosis and meiosis;

(c) explain, using the Laws of Segregation and Independent Assortment, why fertilization and the production of sperm and eggs through meiosis is necessary for species variability;

(d) describe, using words, diagrams, and charts, how a given trait is inherited and expressed;

(e) explain and predict qualitatively and quantitatively, using rules of probability and heredity, the genotype and phenotype of the offspring of parents with given genotypic traits to include dominant-recessive traits, incomplete and co-dominant traits, polygenic traits, and sex-linked and sex-influenced traits;

(f) explain, using the Laws of Segregation and Independent Assortment, how the sex is determined in humans;

(g) describe, using words, diagrams, and charts, how a mutation occurs;

(h) explain and predict, using the relationship between genes and their expression, the effect an environmental change will have on the expression of a given genetic trait;

(i) describe, using words, diagrams, and charts, the process of producing recombinant DNA; and

(j) describe, using words, pictures, and diagrams, how genetic technology is used in treatment of human disease and development of agriculture products;

(4) understand diversity and biological evolution as evidenced by the ability to:

(a) describe in words, pictures, and diagrams the range of physical, behavioral, and biochemical adaptations that can occur in response to environmental stresses for a given species;

(b) explain, using the principles of mutation and natural selection, how a specific adaptation of a given species might have developed in response to environmental stresses;

(c) describe, using words, diagrams, charts, and statistical relationships, the range of phenotypes of a given species in a given environment;

(d) explain and predict, using the principles of mutation, recombination, and natural selection, changes in the range of phenotypes of a species when a given change occurs in the environment of the species;

(e) explain, using the principles of mutation, recombination, and natural selection, why certain species are found in the fossil records relatively unchanged while others are not and others are extinct;

(f) explain and predict, using the evolutionary tree, morphological variations between two or more given species; and

(g) explain the variations in morphological characteristics and DNA composition of two or more given species;

(5) understand the interdependence among living things as evidenced by the ability to:

(a) perform measurements and statistical analyses to describe results of a study investigating the relationship between a given common organism and its environment;

(b) perform measurements and statistical analyses to describe the diversity and number of species in a given ecosystem;

(c) describe, using words, pictures, and diagrams, the cycling of a given substance among living and nonliving components of the biosphere;

(d) describe, using words, pictures, diagrams, and simple mathematical relationships, the cycling of matter and the flow of energy both within a given system, and between the system and the biosphere;

(e) explain, using the relationships between biotic and abiotic components of that system, why the population size and diversity of species is different between two different niches, habitats, ecosystems, or biomes;

(f) explain and predict, using population growth dynamics and interspecific and intraspecific interactions, changes in population size of organisms in an ecosystem for a given change in the biotic and abiotic components of the ecosystem; and

(g) design an experiment to investigate relationships within and among species in a simple ecosystem; and

(6) understand behavior of organisms as evidenced by the ability to:

(a) perform measurements and statistical analyses to describe the physical behavior of animals in a given natural and perturbed situation;

(b) describe, using words, pictures, and diagrams, behaviors of a given animal that allow it to interact with organisms of its own and other species and to respond to environmental changes;

(c) explain and predict, in terms of the principles of animal communication and adaptation, the behavioral responses of an animal to a given set of interactions or environmental changes; and

(d) explain behavioral responses of a given animal in terms of natural selection.

C. A teacher of life science must demonstrate an advanced conceptual understanding of life science and the ability to apply its fundamental principles, laws, and concepts by completing a full research experience. The teacher must:

(1) identify various options for a research experience including independent study projects, participation in research with an academic or industry scientist, directed study, internship, or field study;

(2) select an option and complete a research experience that includes conducting a literature search on a problem;

(3) design and carry out an investigation;

(4) identify modes for presenting the research project; and

(5) present the research project in the selected mode.

Subp. 7. **Subject matter standards for teachers of physics.** A candidate for licensure as a teacher of physics in grades 9 through 12 must complete a preparation program under subpart 2, item C, that must include the candidate's demonstration of the knowledge and skills in items A to C, and subpart 3, items E and F.

A. A teacher of physics must demonstrate a conceptual understanding of physics. The teacher must:

(1) use sources of information to solve unfamiliar quantitative problems and communicate the solution in a logical and organized manner as evidenced by the ability to:

(a) describe, in terms of the known and unknown quantities, a given problem in the appropriate pictorial, graphical, or written form;

(b) qualitatively describe, in appropriate physics terms using motion diagrams, vector force diagrams, energy or momentum diagrams, ray diagrams, or field diagrams as necessary, a given problem situation;

(c) mathematically describe, in terms of the relevant numerical, algebraic, and trigonometric quantities and equations, a given problem;

(d) plan, using words, diagrams, and mathematical relationships, a solution for solving a given problem and verify the solution;

(e) implement, using algebra and manipulation and solution of coupled sets of linear equations, quadratic equations, simple differential equations, and simple integrals as necessary, a solution to a given problem; and

(f) evaluate, in terms of unit consistency, reasonableness, and completeness of solution, the solution of a given problem;

(2) use computers to display and analyze experimental and theoretical data as evidenced by the ability to:

(a) graphically describe data using a computer;

(b) design a mathematical model to provide a reasonable fit to a given set of data;

(c) compute and evaluate the statistical significance of mean and standard deviation for a distribution of data;

(3) estimate common physical properties as evidenced by the ability to:

(a) describe numerically, using reasonable physical estimates, the physical properties of common objects; and

(b) compute and evaluate the reasonableness of calculated physical parameters of common objects; and

(4) develop a plan to ensure a safe environment and practices in all physics learning activities.

B. A teacher of physics must demonstrate a knowledge of physics concepts. The teacher must:

(1) understand linear and rotational motion as evidenced by the ability to:

(a) perform measurements and calculations to describe the linear and angular position, velocity, and acceleration of a given object; the forces and torques acting on an object; and the energy, momentum, and angular momentum of a system before and after an interaction;

(b) describe, using words, pictures and diagrams, graphs, vectors, and mathematical relationships, the motion of a given object;

(c) describe, using words, free-body vector diagrams, and mathematical relationships, the forces acting on each object in a given system of interacting objects and explain, using Newton's Second and Third Laws, the relationships between all the forces;

(d) describe, using words, energy diagrams or graphs, and mathematical relationships, the change of energy of a system and any transfer of energy into or out of a given system of interacting objects;

(e) describe, using words, vector diagrams, and mathematical relationships, the change of linear or angular momentum of a given system and any transfer of momentum into or out of the system of interacting objects;

(f) explain and predict qualitatively and quantitatively, in terms of Newton's Laws, the conservation of energy, and the conservation of momentum, the motion of objects in a given system of interacting objects; and

(g) design a strategy for making an object move in a given way;

(2) understand simple harmonic and wave motion as evidenced by the ability to:

(a) perform measurements and calculations to describe the wavelength, amplitude, period, frequency, and energy of a traveling wave or an object in simple harmonic motion;

(b) describe, using words, force diagrams, energy diagrams or graphs, motion graphs, and mathematical relationships, simple or damped harmonic motion or resonance of a given oscillating system;

(c) explain and predict qualitatively and quantitatively, using the equation of motion, changes in motion of an oscillator in a given system when the intrinsic characteristics of the oscillator change, when a given external force is applied to the oscillator, and when the oscillator loses energy to its surroundings;

(d) design, using words, diagrams or graphs, and mathematical relationships, a system which oscillates at a given frequency or exhibits damped oscillations;

(e) describe a traveling or standing wave in a given medium;

(f) explain and predict qualitatively and quantitatively, using the wave equation of motion and the superposition principle, changes in wave motion when a given traveling wave interacts with a given object or boundary;

(g) explain and predict qualitatively and quantitatively, using the wave equation of motion and the superposition principle, changes in wave motion when a given traveling wave interacts with a second wave; and

(h) explain and predict qualitatively and quantitatively, using the wave equation of motion and the superposition principle, changes in the wave when the source and detector are moving relative to each other;

(3) understand electricity and magnetism as evidenced by the ability to:

(a) perform measurements and calculations to describe time varying or constant values of current, voltage, and power in electric circuits and in magnetic fields;

(b) describe, using words, circuit diagrams, graphs, and mathematical relationships, the current, voltage, resistance, capacitance, or inductance of a given system of circuit elements;

(c) explain and predict qualitatively and quantitatively, using the conservation of charge and the conservation of energy, the current through or the voltage across each element in a given circuit when changes are made to the circuit;

(d) design a circuit in which the current varies in a given way;

(e) explain and predict qualitatively and quantitatively, in terms of Newton's laws and the Lorentz Force, the motion of charges in given electric and magnetic fields;

(f) predict qualitatively and quantitatively, using Gauss's law or Ampere's law, the electric field around a given simple geometric distribution of charges and the magnetic field around a given simple geometric system of current-carrying wires;

(g) predict qualitatively, using Lenz's law and Faraday's Law, the induced currents from a given changing magnetic flux;

(h) design, using simple materials, a working electric motor and an air-core electromagnet that produces a field strength; and

(i) explain, in terms of the motion of charges and the electromagnetic nature of light, how electromagnetic radiation is generated in a given situation;

(4) understand physical and geometrical optics as evidenced by the ability to:

(a) perform measurements and calculations to describe light intensity and polarization of a given light source, the location of images formed by a simple mirror and lens system, and the focal length and magnification of a curved mirror or thin lens;

(b) describe, using words, ray diagrams, graphs, and mathematical relationships, the reflection, refraction, transmission, and absorption of light when it encounters a given macroscopic object, a plane or curved mirror, a boundary between mediums of different indices of refraction, a linear polarizer, a prism, and thin concave and convex lenses;

(c) explain and predict qualitatively and quantitatively, in terms of ray diagrams and the laws of reflection and refraction of light, the location and magnification of a real or virtual image for a given system of mirrors or lenses;

(d) design a system of lenses and mirrors to produce a real or virtual image of a given magnification;

(e) describe, using words, diagrams, and graphs, the interaction of monochromatic light with a given single or pair of parallel slits and with thin films; and

(f) explain and predict qualitatively and quantitatively, using the behavior of waves and the principle of superposition, the change in the resulting light

pattern with given changes in slit width, separation, and the wavelength of the incident light on a system of slits;

(5) understand the kinetic-molecular model of matter and thermodynamics as evidenced by the ability to:

(a) perform measurements and calculations to describe the mass, volume, density, temperature, and heat capacity of a solid, liquid, or gas at constant pressure and the pressure in a gas;

(b) explain qualitatively, using the kinetic-molecular model of matter, a common physical change;

(c) describe, using words, graphs, and mathematical relationships, changes in pressure, volume, or temperature of an ideal gas;

(d) predict, using the First Law of Thermodynamics, the final temperature of a given thermally isolated system of interacting objects and materials;

(e) explain and predict qualitatively and quantitatively, using the First Law of Thermodynamics, the transfer of heat into or out of a given system;

(f) explain, using the First Law of Thermodynamics, the changes of pressure, temperature, and volume for a monatomic ideal gas operating in a Carnot cycle between given states, and describe quantitatively, using words, graphs, and mathematical relationships, the thermal efficiency of the system; and

(g) explain, in terms of the second law of thermodynamics, why energy flows from hot to cold objects; and

(6) understand contemporary physics as evidenced by the ability to:

(a) perform measurements and calculations to detect nuclear radiation in the environment, and determine wavelengths and energy of the emission spectrum of a given gas;

(b) describe, using words, diagrams, and mathematical relationships, the time dilation, length contraction, and momentum and energy of an object of given velocity;

(c) describe, using words, diagrams, and tables, the basic atomic and subatomic constituents of matter;

(d) explain qualitatively, in terms of the standard model, the observed interaction between atomic or subatomic particles in a simple situation;

(e) explain qualitatively, using the quantum nature of light and matter, and the conservation of energy and momentum, the observed interaction between photons and matter in a given situation;

(f) explain, using conservation principles, the observed changes in the matter and energy of a given nuclear process;

(g) predict, using the Heisenberg Uncertainty Principle, the lower limit of size, momentum, energy, or time that could be expected in a given atomic or subatomic measurement or situation; and

(h) describe, in terms of the energy bands and levels in the material, the electrical conductivity of a given conductor, insulator, or semiconductor.

C. A teacher of physics must demonstrate an advanced conceptual understanding of physics and the ability to apply its fundamental principles, laws, and concepts by completing a full research experience. The teacher must:

(1) identify various options for a research experience including independent study projects, participation in research with an academic or industry scientist, directed study, internship, or field study;

(2) select an option and complete a research experience that includes conducting a literature search on a problem;

(3) design and carry out an investigation;

(4) identify modes for presenting the research project; and

(5) present the research project in the selected mode.

Subp. 8. **Continuing license.** A continuing license shall be issued and renewed according to the rules of the Board of Teaching governing continuing licensure.

Subp. 9. **Effective date.** The requirements of this part for licensure as a teacher of science shall be effective on September 1, 2010, and thereafter.

Statutory Authority: *MS s 122A.09; 122A.18*

History: *23 SR 1928; 26 SR 700; 34 SR 595*

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