

CHAPTER 2

TIMSS Advanced 2015 Physics Framework

Lee R. Jones, Gerald Wheeler, and Victoria A.S. Centurino

Similar to the TIMSS Advanced—Mathematics Framework, the assessment framework for TIMSS Advanced—Physics is organized around two dimensions: a content dimension specifying the domains or subject matter to be assessed within physics (i.e., mechanics and thermodynamics, electricity and magnetism, and wave phenomena and atomic/nuclear physics), and a cognitive dimension specifying the domains or thinking processes to be assessed (i.e., knowing, applying, and reasoning). The cognitive domains describe the thinking processes expected of students as they engage with the physics content.

In general, this framework is similar to that used in TIMSS Advanced 2008. However, there have been updates to particular topics to better reflect the content coverage of current high school physics curricula, standards, and frameworks of participating TIMSS Advanced countries. Consideration also was given to current research and initiatives in science and science education, such as the *Framework for K–12 Science Education* (National Research Council, 2012) developed in the United States, the *Physics Higher 2 Syllabus* (Singapore Examinations and Assessment Board, 2013) used in Singapore, the *Physics Curriculum (Secondary 4–6)* (Education Bureau, Hong Kong, SAR, 2007) used in Hong Kong, and the *AP Physics Course Description* (College Board, 2012).

Exhibit 2 shows the target percentages of testing time devoted to each content and cognitive domain for the physics assessment.

Exhibit 2: Target Percentages of the TIMSS Advanced 2015 Physics Assessment Devoted to Content and Cognitive Domains

Content Domains	Percentages
Mechanics and Thermodynamics	40%
Electricity and Magnetism	25%
Wave Phenomena and Atomic/Nuclear Physics	35%

Cognitive Domains	Percentages
Knowing	30%
Applying	40%
Reasoning	30%

TIMSS Advanced—Physics Content Domains

The TIMSS Advanced—Physics Framework includes three content domains: mechanics and thermodynamics, electricity and magnetism, and wave phenomena and atomic/nuclear physics. The content covered in these three domains is very similar to the content coverage in the TIMSS Advanced 2008 Framework, except that the content was organized into four domains in 2008. Organizing the content in three domains will support the reporting of reliable student scores at the physics domain level for TIMSS Advanced 2015. This organization also follows the structure of many current high school physics curricula. In the TIMSS Advanced 2015 Framework, topics that were included in the heat and temperature domain in 2008 are now included in the mechanics and thermodynamics domain, and some topics regarding sound and light, which were included in the mechanics domain and the electricity and magnetism domains, respectively, in 2008, are now included in the domain that includes wave phenomena.

Each of the three content domains in the TIMSS Advanced—Physics Framework is divided into topic areas, and each topic in turn includes several topics. Across the TIMSS Advanced—Physics assessment, each topic receives approximately equal weight in terms of time allocated to assessing the topic.

Mechanics and Thermodynamics

An understanding of forces and motion is fundamental to understanding the other areas of physics. This TIMSS Advanced 2015 domain focuses on three topic areas common to most participating countries' curricula:

- Forces and motion;
- The laws of conservation; and
- Heat and temperature.

Kinematics, dynamics (Newton's three laws of motion), and the law of gravitation are important components of this area. The conservation of certain physical quantities, such as energy or momentum, is a fundamental concept in physics that is expressed by the laws of conservation (energy and momentum) and the first law of thermodynamics. The area of thermodynamics includes mechanisms of heat transfer and how properties of matter change with temperature.

Mechanics and Thermodynamics: Forces and Motion

1. Predict and determine the position, displacement, and velocity of bodies given initial conditions; and use Newton's laws of motion to explain the dynamics of different types of motion and to calculate displacement, velocity, acceleration, distance traveled, or time elapsed.
2. Identify forces, including frictional force, acting on a body at rest, moving with constant velocity, or moving with constant acceleration and explain how their combined action influences the body's motion; and find solutions to problems involving forces.
3. Determine the forces acting on a body moving in a circular path at constant velocity, the body's centripetal acceleration, its velocity, and the time for it to complete a full revolution.
4. Use the law of gravitation to determine the motion of celestial objects and the forces acting on them.

Mechanics and Thermodynamics: The Laws of Conservation

1. Apply the law of conservation of mechanical energy in practical contexts, including finding solutions to problems involving the transformation of potential to kinetic energy and vice versa.
2. Apply the law of conservation of linear momentum in elastic and inelastic collisions.
3. Solve problems using the first law of thermodynamics.

Mechanics and Thermodynamics: Heat and Temperature

1. Demonstrate understanding of mechanisms of heat transfer and the mechanical equivalent of heat (work); and use specific heats or heat capacities to predict equilibrium temperature when bodies of different temperature are brought together.
2. Determine the expansion of solids in relation to temperature change; and use the ideal gas law (in the form $pV/T = \text{constant}$) to solve problems and demonstrate an understanding of the limitations of this law.

Electricity and Magnetism

Electricity and magnetism are core areas of study in physics that have a wide range of practical applications. The TIMSS Advanced 2015 electricity and magnetism domain focuses on the following:

- Electricity and electric circuits; and
- Magnetism and electromagnetic induction.

Important concepts in electricity encompass the behavior of electrostatic charges and their motion in electric circuits, including the role of resistance and energy losses. Understanding the relationship between electricity and magnetism, including the interaction of charged particles with magnetic fields, the production of magnetic fields from current-carrying wires, and induction is central to this domain.

Electricity and Magnetism: Electricity and Electric Circuits

1. Calculate the magnitude and direction of the electrostatic attraction or repulsion between isolated charged particles by application of Coulomb's law.
2. Predict the force on and the path of a charged particle moving in a homogeneous electric field.
3. Solve problems relating current in electrical circuits (and components of circuits) to voltage, resistance, and energy transformation, including using Ohm's Law and Joule's Law.

Electricity and Magnetism: Magnetism and Electromagnetic Induction

1. Predict the force on and the path of a charged particle moving in a homogeneous magnetic field.

2. Demonstrate understanding of the relationship between magnetism and electricity in phenomena such as magnetic fields around electric conductors (Ampere's law), electromagnets, and electromagnetic induction.
3. Solve problems using Faraday's and Lenz' laws of induction.

Wave Phenomena and Atomic/Nuclear Physics

Wave phenomena and atomic/nuclear physics covers much of what is sometimes known as modern physics. This TIMSS Advanced 2015 domain focuses on two topic areas common to most participating countries' curricula:

- Wave phenomena; and
- Atomic and nuclear physics.

The study of wave phenomena provides a bridge between classical and modern physics, and includes mechanical wave phenomena, electromagnetic radiation, as well as refraction, interference, and diffraction. Atomic and nuclear physics form the core of modern physics and include the structure of atomic nuclei, the behavior of electrons, nuclear reactions, and radioactive decay.

Wave Phenomena and Atomic/Nuclear Physics: Wave Phenomena

1. Apply knowledge of mechanical wave phenomena and the relationship between speed, frequency, and wavelength to solve problems.
2. Demonstrate understanding of electromagnetic radiation in terms of waves caused by the interplay between variations in electric and magnetic fields; and identify various types of waves (radio, infrared, visible light, x-rays, gamma rays) by wavelength and frequency.
3. Demonstrate an understanding of thermal radiation in terms of temperature and wavelength of emitted electromagnetic radiation.
4. Demonstrate understanding of reflection, refraction, interference, and diffraction.

Wave Phenomena and Atomic/Nuclear Physics: Atomic and Nuclear Physics

1. Apply knowledge of the structure of atoms and isotopes, atomic number and atomic mass to solve problems; and relate light emission and absorption in the spectrum to the behavior of electrons.

2. Demonstrate understanding of wave-particle duality, including applying knowledge of the photoelectric effect to predict the consequence of changing the incoming intensity or wavelength of light and solving problems involving the wave nature of matter.
3. Demonstrate understanding of nuclear reactions and solve problems involving radioactive decay, such as finding the half-life of a radioactive isotope; and describe the role of nuclear reactions in nature (such as in stars), and explain their practical applications, such as in nuclear reactors.
4. Demonstrate understanding of mass-energy equivalence in nuclear reactions and particle transformations.

TIMSS Advanced—Physics Cognitive Domains

The physics cognitive dimension is divided into three domains based on the thinking processes students are expected to use when encountering the physics items developed for the TIMSS Advanced 2015 assessment. The first domain, knowing, addresses the students' ability to recall, recognize, and describe facts, concepts, and procedures that are necessary for a solid foundation in physics. The second domain, applying, focuses on using this knowledge to generate explanations and solve problems. The third domain, reasoning, includes using evidence and physics understanding to analyze, synthesize, and generalize, often in unfamiliar situations and complex contexts. While there is some hierarchy across the three domains (from knowing to applying to and reasoning), each domain contains items representing a full range of difficulty.

Each content domain includes items developed to address each of the three cognitive domains. Accordingly, the mechanics and thermodynamics domain includes knowing, applying, and reasoning items, as do the other content domains. The following sections further describe the thinking processes defining the cognitive domains. The general descriptions are followed by lists of specific behaviors to be elicited by items that are aligned with each domain.

Knowing

Items in this domain assess students' knowledge of facts, relationships, processes, concepts, and equipment. Accurate and broad-based factual knowledge enables students to successfully engage in the more complex cognitive activities essential to the scientific enterprise.

Recall/Recognize	Identify or state facts, relationships, processes, phenomena, and concepts; identify the appropriate uses for scientific equipment and procedures; and recognize and use scientific vocabulary, symbols, abbreviations, units, and scales.
Describe	Describe or identify descriptions of materials, structures, phenomena, processes, properties, interactions, and relationships.
Provide Examples	Provide or identify examples of processes and phenomena that possess certain specified characteristics; and clarify statement of facts or concepts with appropriate examples.

Applying

Items in this domain require students to engage in applying knowledge of facts, relationships, processes, concepts, equipment, and methods in contexts likely to be familiar in the teaching and learning of physics. This domain includes both quantitative problems requiring a numerical solution and qualitative problems requiring a written descriptive response.

Use Models	Use a diagram or other model to demonstrate knowledge of physics concepts and principles or to illustrate a structure, process, relationship, or system (e.g., electrical circuit, or atomic structure).
Interpret Information	Use knowledge of physics concepts and principles to interpret relevant textual, tabular, pictorial, or graphical information.
Find Solutions	Apply a physical relationship, equation, or formula to find a qualitative or quantitative solution.
Explain	Provide or identify an explanation for an observation or a natural phenomenon using a physics concept, principle, law, or theory.

Reasoning

Items in this domain require students to engage in scientific reasoning to analyze data, draw conclusions, solve problems, and extend their understandings to new situations. In contrast to the more direct applications of physics concepts exemplified in the applying domain, problem-solving situations in the reasoning domain involve unfamiliar or more complicated contexts. Solving such problems may involve a variety of approaches or strategies. Scientific reasoning also encompasses developing hypotheses and designing scientific investigations.

Analyze	Identify the elements of a scientific problem and use relevant information, concepts, relationships, and data patterns to answer questions or solve the problem.
Synthesize	Solve problems that require consideration of a number of different factors or related concepts; and integrate mathematical concepts in the solutions to physics problems.
Design Investigations	Plan investigations or procedures appropriate for answering scientific questions or testing hypotheses; and describe or recognize the characteristics of well-designed investigations in terms of variables to be measured and controlled as well as cause-and-effect relationships.
Formulate Questions/ Hypothesize/Predict	Formulate questions that can be answered by investigation and formulate testable assumptions based on theory, analysis of scientific information, and/or knowledge from observations; and use evidence and conceptual understanding to make predictions about the effects of changes in physical conditions.
Evaluate	Evaluate alternative explanations; and evaluate results of investigations with respect to sufficiency of data to support conclusions.
Draw Conclusions	Make valid inferences on the basis of observations, evidence, and/or understanding of physics concepts; and draw appropriate conclusions that address questions or hypotheses.
Generalize	Make general conclusions that go beyond the experimental or given conditions; and apply conclusions to new physics contexts.
Justify	Use evidence and physics understanding to support the reasonableness of explanations, solutions to problems, and conclusions from investigations.

Science Practices in TIMSS Advanced—Physics

Physicists engage in scientific inquiry by following key science practices that enable them to explore physical phenomena and answer questions about those phenomena. Students of physics must become highly proficient at these practices to develop an understanding of how the scientific enterprise is conducted. These practices include skills from across mathematics and science coursework that students use in a systematic way to conduct scientific inquiry. Five science practices that are fundamental to scientific inquiry are represented in TIMSS Advanced 2015:

1. **Asking questions based on observations**—Scientific inquiry includes observations of physical phenomena with unfamiliar characteristics or properties, and studying existing data sets in detail. These observations, together with existing knowledge of physics concepts, lead to questions, which are used to formulate testable hypotheses to help answer those questions.
2. **Generating evidence**—Answering research questions and testing hypotheses requires designing and executing systematic investigations and controlled experiments (including identifying independent and dependent variables). Scientists must use their knowledge of physics concepts and physical phenomena to determine the appropriate approach to an investigation, including deciding on the evidence to be gathered, understanding what instrumentation and procedures are appropriate to use in data collection, and knowing the level of precision and accuracy needed in the data collection.
3. **Working with data**—Once the data are collected, scientists summarize the data in various types of visual displays. They describe and summarize trends in the data, recognize patterns in the data, interpolate and extrapolate from the data, explore relationships between variables, and determine which patterns and relationships may be worth exploring further. In addition, they evaluate the data for consistency with predictions, and consider when revisions to the initial hypothesis might be needed.
4. **Answering the research question**—Scientists use evidence from observations and investigations together with science knowledge to answer the questions they have posed and support or refute hypotheses.
5. **Making an argument from evidence**—Scientists use evidence and understanding of physics concepts to develop explanations and models of physical phenomena, identify gaps or weaknesses in scientific explanations or arguments, justify and support the reasonableness of their explanations, models, and conclusions, and extend these to new situations.

These science practices cannot be assessed in isolation, but must be assessed in the context of one of the TIMSS Advanced—Physics content domains, and drawing upon the range of thinking processes specified in the cognitive domains. Therefore, some items in TIMSS Advanced—Physics will assess one or more of these science practices as well as content specified in the content domains and thinking processes specified in the cognitive domains.