02 Momentum and Energy

Content Area: **Science**
Course(s): **Physics H**
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Standards

SCI.HS.ETS1.C	Optimizing the Design Solution
SCI.HS.PS2.A	Forces and Motion
SCI.HS-PS2-2	Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
SCI.HS-PS2-3	Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.
SCI.HS.ETS1.A	Defining and Delimiting Engineering Problems
SCI.HS.PS3.A	Definitions of Energy
SCI.HS-PS3-2	Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).
SCI.HS-PS3-3	Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
SCI.HS.PS3.B	Conservation of Energy and Energy Transfer
	Using Mathematics and Computational Thinking
	Cause and Effect
	Engaging in Argument from Evidence
SCI.HS.PS3.D	Energy in Chemical Processes
	Constructing Explanations and Designing Solutions
	Developing and Using Models
	Systems and System Models
	Energy and Matter
SCI.HS-ESS3-2	Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.
SCI.HS.ESS3.A	Natural Resources
SCI.HS-ETS1-2	Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
SCI.HS-ETS1-4	Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.
SCI.HS.ETS1.B	Developing Possible Solutions

Enduring Understandings

1. Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. In any system, total momentum is always conserved. If a system interacts with objects outside itself,

the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.

2. Design criteria and constraints, which typically reflect the needs of the end-user of a technology or process, address such things as the product's or system's function (what job it will perform and how), its durability, and limits on its size and cost. Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.

3. Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. But whatever the scale, the first thing that engineers do is define the problem and specify the criteria and constraints for potential solutions.

4. The aim of engineering is not simply to find a solution to a problem but to design the best solution under the given constraints and criteria. Optimization can be complex, however, for a design problem with numerous desired qualities or outcomes. Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. The comparison of multiple designs can be aided by a trade-off matrix. Sometimes a numerical weighting system can help evaluate a design against multiple criteria. When evaluating solutions, all relevant considerations, including cost, safety, reliability, and aesthetic, social, cultural, and environmental impacts, should be included. Testing should lead to design improvements through an iterative process, and computer simulations are one useful way of running such tests.

5. Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. "Mechanical energy" generally refers to some combination of motion and stored energy in an operating machine. "Chemical energy" generally is used to mean the energy that can be released or stored in chemical processes, and "electrical energy" may mean energy stored in a battery or energy transmitted by electric currents. Historically, different units and names were used for the energy present in these different phenomena, and it took some time before the relationships between them were recognized. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as either motions of particles or energy stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.

6. Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. The availability of energy limits what can occur in any system. Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). Any object or system that can degrade with no added energy is unstable. Eventually it will do so, but if the energy releases throughout the transition are small, the process duration can be very long (e.g., long-lived radioactive isotopes).

7. Force fields (gravitational, electric, and magnetic) contain energy and can transmit energy across space

from one object to another. When two objects interacting through a force field change relative position, the energy stored in the force field is changed. Each force between the two interacting objects acts in the direction such that motion in that direction would reduce the energy in the force field between the objects. However, prior motion and other forces also affect the actual direction of motion.

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

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

10. Resource availability has guided the development of human society. All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks, as well as benefits. New technologies and regulations can change the balance of these factors.

11. Complicated problems may need to be broken down into simpler components in order to develop and test solutions. When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. Testing should lead to improvements in the design through an iterative procedure.

12. Both physical models and computers can be used in various ways to aid in the engineering design process. Physical models, or prototypes, are helpful in testing product ideas or the properties of different materials. Computers are useful for a variety of purposes, such as in representing a design in 3-D through CAD software; in troubleshooting to identify and describe a design problem; in running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.

Essential Questions

1. How can one predict an object’s continued motion, changes in motion, or stability?

2. How do engineers solve problems?

3. What is a design for?

4. What are the criteria and constraints of a successful solution?

5. How can the various proposed design solutions be compared and improved?

6. How is energy transferred and conserved?

7. What is energy?

8. What is meant by conservation of energy?
9. If energy is conserved, why do people say it is produced or used?
10. How is energy transferred between objects or systems?
11. How are forces related to energy?
12. How do humans depend on Earth's resources?
13. What is the process for developing potential design solutions?

Knowledge and Skills

Knowledge:

1. Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. (DCI PS2.A Forces and Motion)
2. If a system interacts with objects outside of itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system. (DCI PS2.A Forces and Motion)
3. An isolated system is one in which the objects interact only with each other and not with the environment, or the sum of external forces exerted on it is zero.
4. Mass is constant in an isolated system. If the system is not isolated and its mass changes, we can always find the system in which the mass is constant.
5. Linear momentum, p→ is a vector quantity that is the product of an object's mass, m, and velocity, v→.
6. The total momentum of the system is the sum of the momenta of all objects in the system.
7. Impulse, J→ is the product of the average external force F→v exerted on an object during a time interval Δt and that time interval.
8. The change in momentum of a system is equal to the net external impulse exerted on it.
9. If the net impulse is zero, then the momentum of the system is constant.
10. If the objects outside the system exert forces on the system and change its momentum, we can always redefine the system by including all interacting objects to keep the momentum of this new system constant. Therefore, momentum is a conserved quantity.
11. To determine the energy of a system, one must first choose a system. Any choice is allowable, but given the objective, often certain choices of system are better than others.
12. Total energy is a property of a system. Different forms of energy describe the interactions between

objects in the system and their motion. The various forms of energy can be converted from one to another within a system.

13. External objects (part of the environment) can do work on the system (positive or negative) and thus change the system's total energy. Objects within the system cannot do work on the system.

14. Work is a way to change the energy of a system. Work is done on a system when an external object exerts a force of magnitude F on an object in the system as it undergoes a displacement of magnitude d. The work depends on the angle theta between the directions of F and d. Work is a scalar quantity.

15. Gravitational potential energy is the energy that a system has due to the relative separation of two objects with mass. It is a scalar quantity. Gravitational Potential Energy depends on the gravitational interaction of the objects. A single object cannot have gravitational potential energy.

16. Kinetic energy is the energy of an object of mass m moving at speed v. It is a scalar quantity.

17. Elastic potential energy is the energy of a stretched or compressed elastic object.

18. Internal energy is the energy of motion and interaction of the microscopic particles making up the objects in the system.

19. Total energy is the sum of all the energies in the system.

20. The energy conversions within the system and the changes of the total energy due to work done by external forces can be represented by a bar chart.

21. The energy of a system changes when external forces do work on it. Internal forces do not change the energy of the system. When there are no external forces doing work on the system, the system's energy is constant.

22. In cases that involve friction, we include both surfaces of interacting objects in the system. Thus when one object slides across the surface of the other object, there is no force of friction doing work on the system (this force is an internal force) but mechanical energy if converted into internal energy of the system.

23. Elastic collisions occur when momentum and kinetic energy of the system are constant - there are no changes in internal energy.

24. Inelastic collisions occur when momentum is constant but kinetic energy is not - the internal energy increases and kinetic energy decreases.

25. Totally inelastic collisions occur when the colliding objects stick together. The momentum is constant but the kinetic energy is not.

26. Power is the rate of energy conversion, or rate of work done on a system during a process.

27. Criteria and constraints also include satisfying requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (DCI ETS1.A Defining and Delimiting an Engineering Problem)

28. Criteria may be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade offs) may be needed. (DCI ETS1.C Optimizing

the Design Solution)

29. Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. (DCI PS3.A Definitions of Energy)

30. At the microscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (DCI PS3.A Definitions of Energy)

31. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. (DCI PS3.A Definitions of Energy)

32. Although energy cannot be destroyed, it can be converted to less useful forms - for example, to thermal energy in the surrounding environment. (DCI PS3.D Energy in Chemical Processes)

33. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (DCI PS3.B Conservation of Energy and Energy Transfer).

34. Uncontrolled systems always evolve toward more stable states - that is, toward more uniform energy distribution (e.g. water flows downhill, objects hotter than their surrounding environment cool down.) (DCI PS3.B Conservation of Energy and Energy Transfer).

35. All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors. (DCI ESS3.A Natural Resources)

36. When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (DCI ETS1.B Developing Possible Solutions)

Skills :

1. Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.

2. Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.

3. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

4. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

5. Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.

6. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem

with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Transfer Goals

Mechanism and explanation. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.

Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.

Patterns Flows, cycles, and conservation. Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.

Resources

Core Resource: Physics, Cutnell & Johnson (10th edition)

Supplemental Resources:

- Physics Union Mathematics (PUM), Rutgers University
- Physics Active Learning Guide, Pearson
- Phet Simulations
  - Collisions
  - Energy Skate Park
- PIVOT Interactives
- The Physics Classroom
- Web Assign

- OPhysics Interactive Physics Simulations
- The Universe and More Interactive Physics Resources
- New York Times article: “Overlooked No More: Eunice Foote Climate Scientist Lost to History” April 21, 2020
- Fourth National Climate Assessment
- New Jersey Climate Data
- TIPERs (Tasks Inspired by Physics Education Research), Sensemaking Tasks for Introductory Physics
- Physics Aviary

Assessments

https://docs.google.com/document/d/1wR7bQF-8AQoRrt0g4C3hKja0yjwDjC9_BiAmONWbTcI/edit?usp=sharing

Modifications

https://docs.google.com/document/d/1ODqaPP69YkcFiyG72fIT8XsUIe3K1VSG7nxuc4CpCec/edit?usp=sharing