Energy Conversion

Unit: Thermodynamics

NGSS Standards/MA Curriculum Frameworks (2016): HS-PS3-1

AP® Physics 2 Learning Objectives/Essential Knowledge (2024): N/A

Mastery Objective(s): (Students will be able to…)

- Describe the conversion of energy between heat and other forms.

Success Criteria:

- Descriptions & explanations account for observed behavior.

Language Objectives:

- Describe and explain an example of conversion of heat into mechanical work.

Tier 2 Vocabulary: heat, energy

Labs, Activities & Demonstrations:

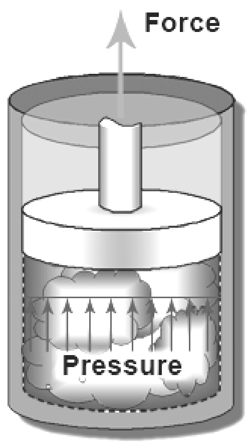
- steam engine
- fire syringe
- metal spheres & paper

Notes:

The law of conservation of energy states that total energy is always conserved, but that energy can be converted from one form to another.

We have already seen this in mechanics with the conversion between gravitational potential energy and kinetic energy.

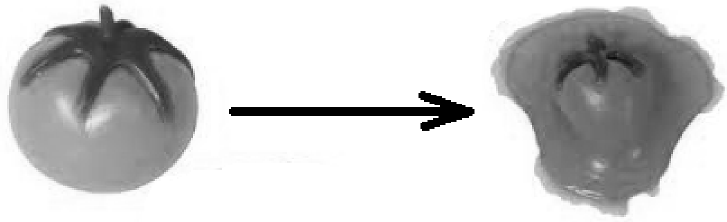
Heat is energy. Like other forms of energy, it can do work. For example, in a steam engine, heat is used to boil water in a sealed container. As more water boils, there is more gas in the boiler, which makes the pressure increase. If the gas can only expand by pushing against something (like a piston), the force from the pressure can do work by moving the piston and whatever it's connected to.



In mechanics, recall that collisions can be elastic or inelastic. In an elastic collision, kinetic energy is conserved; in an inelastic collision, some of the kinetic energy is converted to other forms, mostly heat.

We can use the law of conservation of energy to estimate the amount of energy converted to heat in a completely inelastic collision.

Consider a 0.150 kg tomato hitting the wall at a velocity of $20.0\,\frac{\text{m}}{\text{s}}$.



After the collision, the velocity of the tomato and the wall are both zero. This means the kinetic energy of the tomato after the collision is zero. Because energy must be conserved, this means all of the kinetic energy from the tomato must have been converted to heat.

$$E_k = \tfrac{1}{2}mv^2$$

$$E_k = (\tfrac{1}{2})(0.150)(20.0)^2 = 30.0\text{ J}$$

Now consider the same tomato with a mass of 0.150 kg and a velocity of $20.0\,\frac{\text{m}}{\text{s}}$ hitting a 1.00 kg block of wood that is initially at rest. This is still an inelastic collision, but now the wood is free to move, which means it has kinetic energy after the collision.

To solve this problem, we need to use conservation of momentum to find the velocity of the tomato + wood after the collision, and then use the velocity before and after to calculate the change in kinetic energy.

Before the collision:

$$\vec{p} = m_t\vec{v}_t + \cancelto{0}{m_w\vec{v}_w}$$

$$\vec{p} = (0.150)(+20.0) + 0 = +3.00\text{ N}\cdot\text{s}$$

$$K = \tfrac{1}{2}m_t v_t^2 + \tfrac{1}{2}\cancelto{0}{m_w v_w^2}$$

$$K = (\tfrac{1}{2})(0.150)(20.0)^2 + 0 = 30.0\text{ J}$$

After the collision:

$$\vec{p} = (m_t + m_w)\vec{v}$$

$$+3.00 = (0.150 + 1.00)\vec{v} = 1.15\vec{v}$$

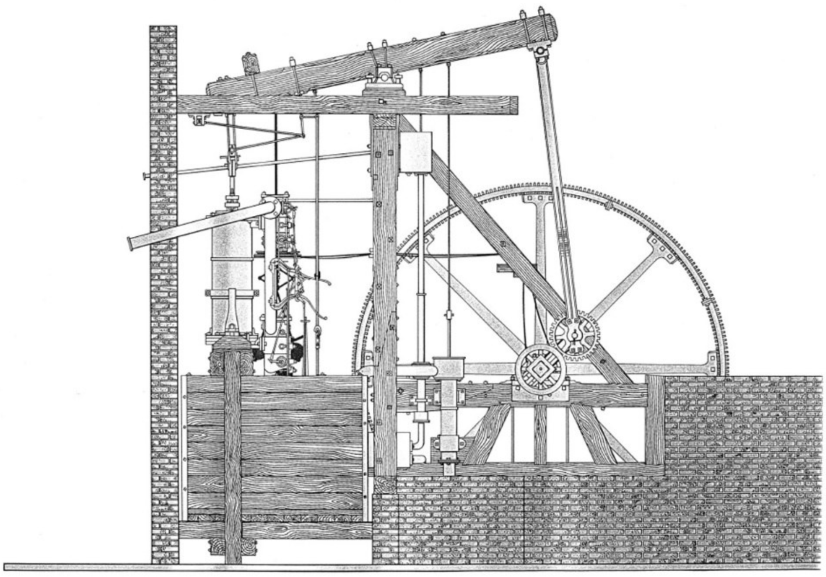
$$\vec{v} = +2.61\,\tfrac{\text{m}}{\text{s}}$$

$$K = \tfrac{1}{2}mv^2$$

$$K = (\tfrac{1}{2})(1.15)(2.61)^2 = 3.91\text{ J}$$

This means there is 30.0 – 3.91 = 26.1 J of kinetic energy that is "missing" after the collision. This "missing" energy is mostly converted to heat. If you could measure the temperature of the tomato and the wood extremely accurately before and after the collision, you would find that both would be slightly warmer as a result of the "missing" 26.1 J of energy.

The first instance of a machine using heat to do work was in 1698, when Thomas Savery patented a steam-driven water pump. In 1769, Scottish engineer James Watt and investor John Roebuck patented a steam engine that could be used for a variety of purposes, including running sawmills, cotton mills, and anything else that required a large amount of force. Watt built his first prototype steam engine in 1788.



James Watt's prototype steam engine, 1788

The invention of the steam engine was a significant factor in the spread of the industrial revolution, and all of the societal changes that went with it.

Thermodynamics is the study of heat energy and its conversion to other forms of energy. In chemistry, thermodynamics is thermal energy that drives chemical reactions. In physics, thermodynamics is thermal energy that can be converted to mechanical work (which you may recall from physics 1, is a force applied over a distance).