Energy Conversion

Unit: Heat & Thermodynamics

NGSS Standards: HS-PS3-1

MA Curriculum Frameworks (2006): N/A

AP Physics 2 Learning Objectives: 5.B.4.2, 5.B.5.4, 5.B.5.5

Knowledge/Understanding:

- conversion of energy between forms

Language Objectives:

- Accurately describe the law of conservation of energy, using appropriate academic language.

Labs, Activities & Demonstrations:

- steam engine
- fire syringe
- metal spheres & paper
- hit clay/silly putty multiple times with a hammer (requires temperature probe)

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.

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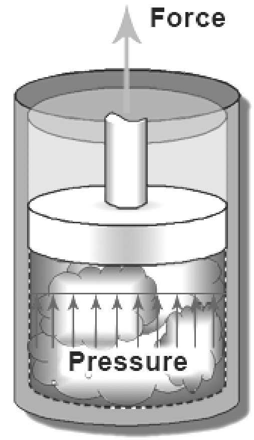
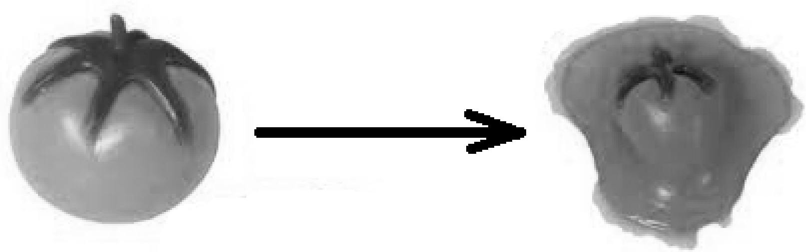
Heat is energy. Like other forms of energy, it can do work. For example, in a steam engine, heat is used to boil water in a sealed container. As more water boils, there is more gas in the boiler, which makes the pressure increase. If the gas can only expand by pushing against something (like a piston), the force from the pressure can do work by moving the piston and whatever it's connected to. (We will revisit the concept of pressure as a force when we study fluid mechanics. For now, it's enough to understand that heat energy can be converted to kinetic energy.)



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 "splat ball" hitting the wall at a velocity of $20.0\frac{m}{s}$.



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

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

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

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Now consider the same splat ball with a mass of 0.150 kg and a velocity of $20.0\,\frac{m}{s}$ hitting a 1.00 kg piece 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 splat ball + wood after the collision, and then use the velocity before and after to calculate the change in kinetic energy.

Before the collision:

$$\vec{p} = m_{sb}\vec{v}_{sb} + m_w \cancelto{0}{\vec{v}_w}$$
$$\vec{p} = (0.150)(+20.0) + 0 = +3.00\ \text{N}\cdot\text{s}$$

$$E_k = \tfrac{1}{2}m_{sb}v_{sb}^2 + \tfrac{1}{2}m_w \cancelto{0}{v_w^2}$$
$$E_k = (\tfrac{1}{2})(0.150)(20.0)^2 + 0 = 30.0\ \text{J}$$

After the collision:

$$\vec{p} = (m_{sb} + m_w)\,\vec{v}$$
$$+3.00 = (0.150 + 1.00)\,\vec{v} = 1.15\vec{v}$$
$$\vec{v} = +2.61\,\tfrac{m}{s}$$

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

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 "splat ball" and the wood extremely accurately before and after the collision, you would find that both would be warmer as a result of the "missing" 26.1 J of energy.

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