

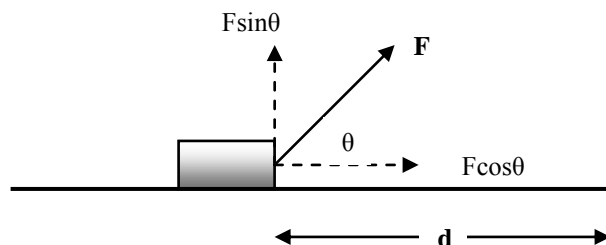
## Pre-AP Physics Ch 5 Notes – Work and Energy, Ch. 10-11: Thermodynamics and Heat

“*Work*” has a variety of meanings in every day language. In physics, its meaning is *VERY* specific.

### Work

- **Work** is energy transferred by a force acting through a distance. *Work* is the scalar product of the *force* acting on an object and the *displacement* through which it acts. **Work** is calculated by multiplying the displacement times the component of force *parallel* to the displacement. Since work is a *scalar quantity* it has no direction associated with it. The units for work are  $\text{N} \cdot \text{m} = \text{J}$  (joule). One joule is about the amount of work you do in lifting your calculator to a height of one meter.

$$W = \mathbf{F} \cdot \mathbf{d} = Fd \cos \theta$$



- $\theta$  is the angle between the applied force and the objects displacement.
  - **When  $F$  is parallel to the displacement**,  $\theta = 0$ , and  $\cos 0 = 1$ , and  $\mathbf{W} = \mathbf{F}\mathbf{d}$ .
  - **Forces perpendicular to the motion of an object do no work** ( $\theta = 90^\circ$ ,  $\cos 90^\circ = 0$ , therefore  $W = 0$ ).
  - **Forces applied to objects at rest do no work** ( $W = Fd$ ; for an object at rest,  $d = 0$ , therefore  $W = 0$ ).
- **The sign of work is important.** Work can either be positive or negative, depending on whether the component of force is in the same direction (+) or opposite direction (-) of the displacement. **Kinetic friction does negative work.** It is negative because the force is **OPPOSITE** to the direction of motion.
- **Example 1.** Calculate the amount of work done by each force acting on a vacuum cleaner as it is pulled at constant velocity 3.0 m by a force of 50.0 N at an angle of  $30.0^\circ$  above the horizontal?

### Work-energy theorem and kinetic energy

- **Energy** is the ability to do work, and when work is done, there is always a transfer of energy. Energy can take on many forms, such as potential energy, kinetic energy, and heat energy. The unit for energy is the same as the unit for work, the *joule*. This is because *the amount of work done on a system is exactly equal to the change in energy of the system.* This is called the *work-energy theorem*.
- **Kinetic energy** is the energy an object has because it is moving. In order for a mass to gain kinetic energy, positive work must be done on the mass to push it up to a certain speed. In order for a mass to lose kinetic energy, negative work must be done on the mass to slow it down. The work-energy theorem states that the change in kinetic energy of an object is exactly equal to the work done on it, assuming there is no change in the object's potential energy. *Kinetic energy depends on speed and mass.* Note that  $K$  is  $\propto$  to mass and  $K$  is  $\propto$  to  $v^2$  (double the mass— $K$  doubles, double the velocity— $K$  quadruples).

$$W = \Delta KE = \frac{1}{2} m v_f^2 - \frac{1}{2} m v_o^2$$

- The work done on a system can also be converted into **heat** energy, and usually some of the work is.
- **Example 2.** What is the minimum amount of energy required to accelerate a 3.0 g bullet from rest to a speed of 40.0 m/s?

## Potential energy

- **Potential energy** is the energy a system has because of its position or configuration. When you stretch a rubber band, you store energy in the rubber band as elastic potential energy. When you lift a mass upward against gravity, you do positive work on the mass, gravity does negative work, and, as long as there is no change in speed, the net work is zero. If you release the mass, gravity will do positive work on the mass as it falls. Thus, the work you do on the mass gives it potential energy relative to the lower position. To lift it, you must apply a force equal to the weight  $mg$  of the mass through a displacement height  $h$ , and the work done in lifting the mass is

$$W = Fd = (mg)h$$

which must also equal its potential energy

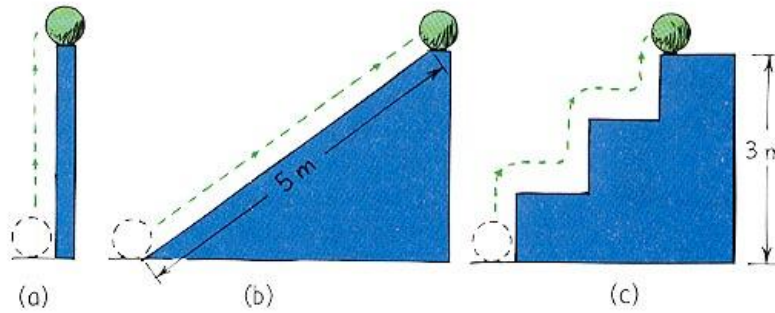
$$PE = mgh$$

- There are three types of potential energy we will study (**gravitational, elastic, and electric**).

1. **Gravitational potential energy** is energy associated with an object due to the object's position relative to a gravitational source.

$$U_g = mgh$$

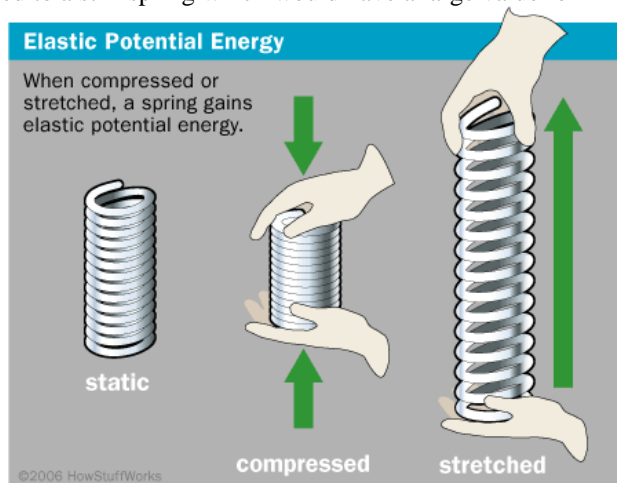
- The higher an object is, the more gravitational PE it has.  $h$  is relative since what we are concerned with is actually  $\Delta h$ . The amount of work required to lift a mass to a certain height against gravity only depends upon the weight of the object and  $\Delta h$ , not the path taken. The change in gravitational potential energy is the same for all three cases below.



2. **Elastic potential energy** is energy stored in a deformed elastic object. Stretch or compress a spring (or an elastic object) and it will try to return to its relaxed length; therefore, there is energy stored in a spring not at its equilibrium position (**elastic potential energy**).

$$U_{\text{elastic}} = \frac{1}{2}kx^2$$

- $x$  is the displacement from the spring's relaxed length
- $k$  is the **spring constant** which depends on the nature of the spring; flexible springs would have a small value of  $k$  compared to a stiff spring which would have a large value for  $k$



3. **Electric potential energy will be covered the second semester**

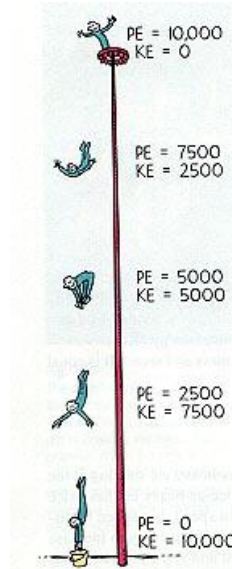
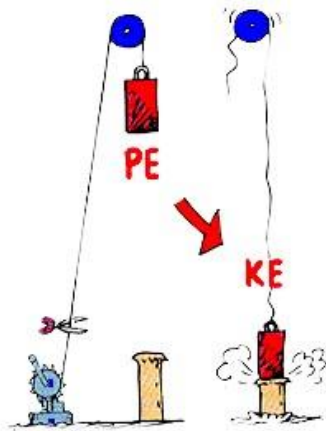
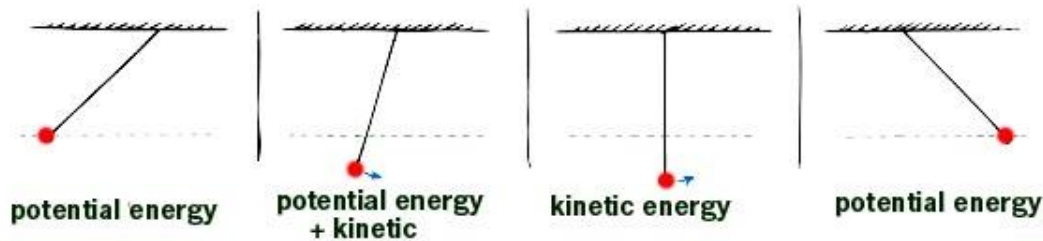
### Conservative and Non-conservative Forces

- A force is **conservative** when the work it does is independent of the path between the object's initial and final positions (*gravity, electric, and elastic*). For example, work done *against* gravity does NOT depend on a path taken, it simply depends on  $\Delta h$ . A potential energy can be defined for a conservative force, but not for a non-conservative force.
- **NON-conservative forces** (friction for example) do depend on the path taken.  $W = Fd \cos \theta$  and if  $d$  increases so does the work. Non-conservative forces include friction, air resistance, tension, motor or rocket propulsion, push or pull by person and can either add (positive work) or remove (negative work) energy from the system.

### Conservation of mechanical energy

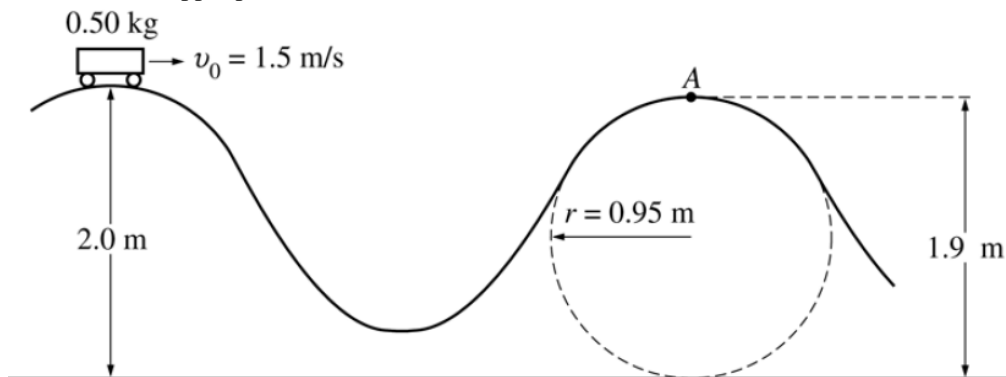
- When we say something is **conserved**, we mean that it remains constant. The **first law of thermodynamics** (law of conservation of energy) states that energy cannot be created nor destroyed, just change forms. When work is done on a system, the energy of that system changes from one form to another, but the *total amount* of energy remains the same. If only conservative forces do work on an object, mechanical energy is also conserved. **Mechanical energy** is defined as the sum of the kinetic and potential energies of an object. If mechanical energy is conserved, speed of an object can easily be calculated since only the starting and ending positions are needed to find the change in potential energy (the path the object takes is irrelevant). Energy conservation occurs even when **acceleration is not constant**.
- **Conservation of mechanical energy and energy transformations**

$$KE_i + PE_i = KE_f + PE_f$$



- **Example 3.** Starting from rest, a 25.0 kg child zooms down a frictionless slide from an initial height of 3.00 m. What is her speed at the bottom of the slide?

- **Example 4.** A designer is working on a new roller coaster, and she begins by making a scale model. On this model, a car of total mass 0.50 kg moves with negligible friction along the track shown in the figure below. The car is given an initial speed  $v_0 = 1.5 \text{ m/s}$  at the top of the first hill of height 2.0 m. Point A is located at a height of 1.9 m at the top of the second hill, the upper part of which is a circular arc of radius 0.95 m.



- Calculate the speed of the car at point A.
- In order to stop the car at point A, some friction must be introduced. Calculate the work that must be done by the friction force in order to stop the car at point A.
- How could the track be modified in order to increase the speed of the car at point A?

### Power

- Work can be done slowly or quickly, but the time taken to perform the work doesn't affect the amount of work which is done, since there is no element of time in the definition for work. However, if you do the work quickly, you are operating at a higher power level than if you do the work slowly. **Power is defined as the rate at which work is done.** Oftentimes we think of electricity when we think of power, but it can be applied to mechanical work and energy as easily as it is applied to electrical energy. The equation for power is

$$P = \frac{\text{Work}}{\text{time}} \quad \bar{P} = \frac{\Delta W}{\Delta t} \quad P = Fv$$

and has units of joules/second or *watts* (W). A machine is producing one watt of power if it is doing one joule of work every second. A 75-watt light bulb uses 75 joules of energy each second.

- **Example 5.** A student weighing 700 N climbs at constant speed to the top of an 8.0 m vertical rope in 10 s. Calculate the average power expended by the student to overcome gravity.

**HW Textbook Practice Problems Ch. 5: #'s 7, 8, 9, 19, 35, 37, 39, 52, 53, 57, 61, and 62.**

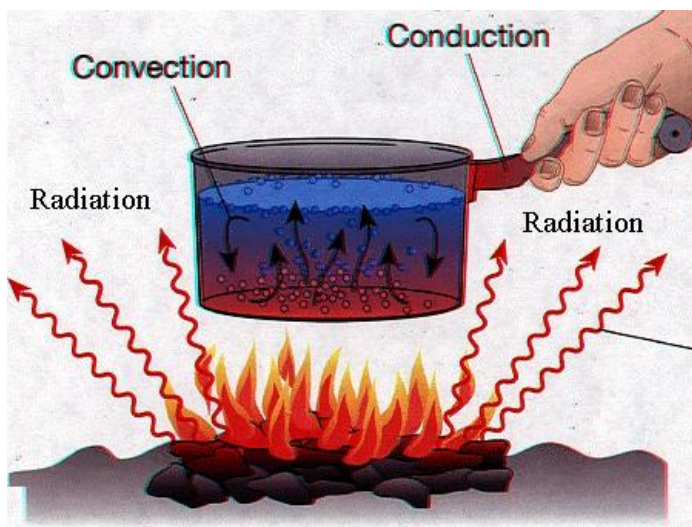
## Chs 10-11 – Heat Transfer and Thermodynamics

### Heat and Internal Energy

- **Heat** is energy exchanged between objects because of a temperature difference. *Heat originates in the internal energy* of a substance. *Internal energy* is the sum of all the kinetic and potential energies associated with the molecules of the substance. For gases, *internal energy is directly proportional to temperature*. When heat flows in circumstances where the work is negligible, the *internal energy of the hot substance decreases and the internal energy of the cold substance increases*. While heat originates in the internal energy of a substance, *it is not correct to say that a substance contains heat*. The substance has internal energy, not heat. *Heat is used only when referring to the energy in transit from hot to cold*.
- Remember that the SI unit for energy (heat, internal energy, work) is the **J** (joule). You may be familiar with some of the older units (calorie or BTU) used for heat which were developed while there was still a big misunderstanding regarding heat and work energy. James Joule (1818-1889) first quantified the relationship between mechanical energy and thermal energy.

### Three methods of heat transfer

1. **Conduction** is heat transferred directly through a material or from one material to another material in direct contact with each other by the process of molecule to molecule collisions (no net flow of material other than possibly expansion). Metals are good conductors and gases are poor conductors. Solids such as wood, styrofoam, etc. are poor conductors (good insulators) because of the air or fluid spaces within them.
2. **Convection** is heat transferred by the bulk movement of the molecules in a fluid (gas or liquid) due to different densities within a fluid caused by different temperatures within the fluid. Typically the hotter the material the less dense it is. The less dense material rises transferring its heat to the upper layers. Convection currents are formed transferring the hotter (less dense) material upwards and the cooler (denser) material downwards.
3. **Radiation** is a process of heat transfer that *does NOT involve matter*, but rather electromagnetic radiation. We will cover electromagnetic radiation in chapters 14 and 23.



### Specific heat

- **Specific heat** is the quantity of heat required to raise a specific amount of a substance (usually 1kg or 1g but sometimes 1 mol) by one kelvin. The specific heat for water is **4,186 J/kg • °C for water**. Water's specific heat is unusually high due to hydrogen bonding. Metals have a much lower specific heat which is why they are good thermal conductors. Items with a high specific heat are good insulators.

$$Q = mc\Delta T$$

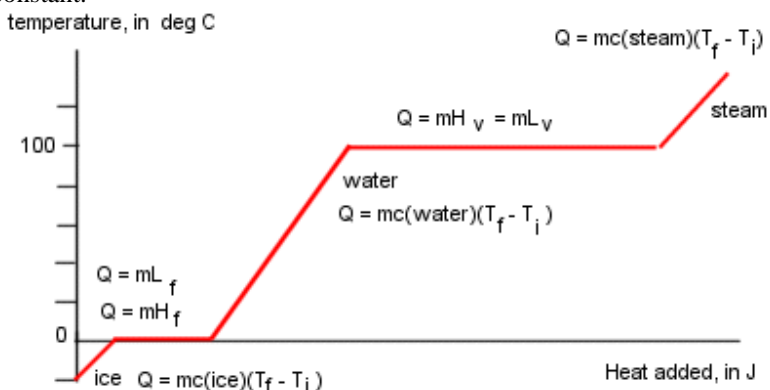
- **Q** = quantity of heat energy transferred; units are J; Q (+) if heat flows IN, Q (-) if heat flows OUT
- **c** = specific heat; table on pg 372 which lists the specific heat of some common substances
- **m** = mass (watch the units – usually kg, but could be g, or, *could be moles where “n” is used instead of “m”*)
- **Example 1.** A 0.50 kg ball thrown vertically downward strikes a horizontal surface with a speed of 15 m/s. It then bounces, and reaches a maximum height of 5.0 m. Neglect air resistance.
  - a. What is the speed of the ball immediately after it rebounds from the surface?
  - b. How much of the ball's kinetic energy is lost during the bounce?
  - c. If the specific heat of the ball is 1,800 J/kg °C, and if all of the lost energy is absorbed by the molecules of the ball, by how much does the temperature of the ball increase?

## Latent heat and phase changes

- If heat is added to a substance, the temperature increases (average kinetic energy of the molecules increase) **unless the substance is going through a phase change**. For instance, if heat is added to a solid at its melting point, the molecules move apart and gain more potential energy, thus no increase in kinetic energy and no increase in temperature. From chemistry, you should be familiar with  $\Delta H_{\text{fusion}}$  and  $\Delta H_{\text{vaporization}}$ . In Physics, we use  $L_f$  and  $L_v$ .

$$Q = mL$$

- $L_f$  (**latent heat of fusion**) refers to the amount of heat required to change the phase of a substance at its melting/freezing point.  $L_v$  (**latent heat of vaporization**) refers to the amount of heat required to change the phase of a substance at its boiling/condensing point.  $L_s$  (**latent heat of sublimation**) refers to the amount of heat required for objects to sublime (change directly from a solid to a gas without going through a liquid phase; for example, carbon dioxide).
- During a phase change, the temperature remains constant UNTIL the last molecules have completed the phase change (plateaus on a phase change diagram)**. This is because potential energy is increasing while kinetic energy remains constant.



## Thermodynamics

- Thermodynamics is the study of the fundamental laws that govern heat and work. Heat can be used to do work (heat engine) and work can transfer energy to a substance (increasing its internal energy) and then flow to another substance in the form of heat (refrigerator).

### Four laws of thermodynamics

- Zeroth law** states that if two systems are in thermal equilibrium with a third system (same temperature), then they are in thermal equilibrium with each other.

- First law** is the law of conservation of energy. Mathematically stated

$$\Delta U = Q + W$$

- In a certain process, 400 J of heat is added to a system and the system simultaneously expands doing 100 J of work. What is the change in internal energy of the system?

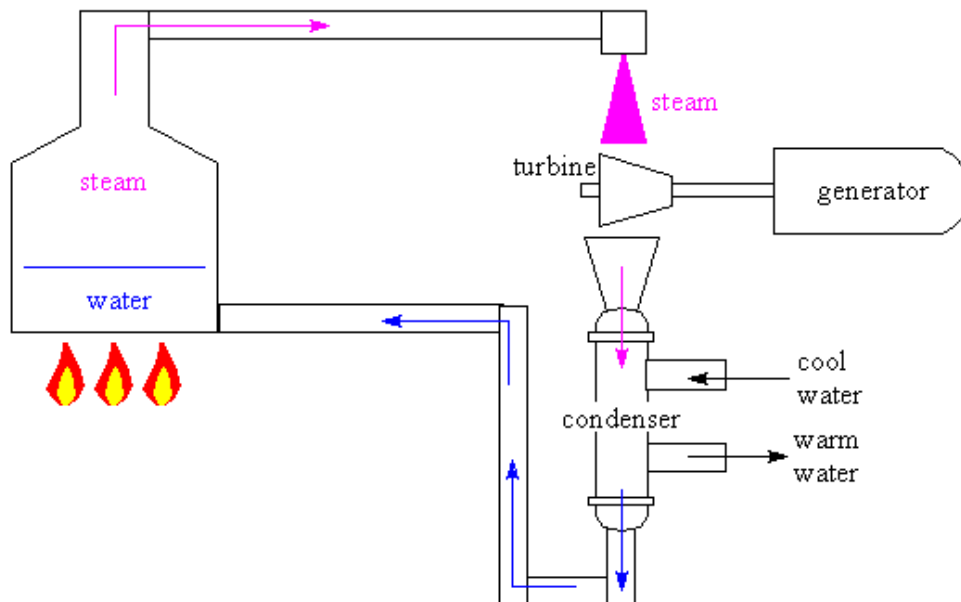
- Second law**

- Heat flows spontaneously from a hot object to a cold one, but not the reverse.
- No heat engine operating in a cycle can absorb thermal energy from a reservoir and just perform an equal amount of work. There cannot be a 100% efficient heat engine – one that can transform all heat into work. Prohibits perpetual motion machines.
- All spontaneous processes proceeding in an isolated system lead to an increase in entropy. The entropy of the universe is always increasing.

- Third law** states that it is not possible to lower the temperature of any system to absolute zero in a finite number of steps.

## Heat engines

- Heat engines take many forms, from the internal combustion engine in the family car to the giant turbines that generate electricity for our homes. What they have in common is they convert thermal energy into mechanical energy by the expansion of a gas. When a gas is heated (thermal energy) it can expand causing motion (mechanical energy). In an internal combustion engine the heated gas in the piston chamber pushes the piston downward. In a steam engine coal is burned (or some other source of energy) which heats water producing steam (hot reservoir) that flows to a lower temperature (cold reservoir or heat sink) and in the process causes a turbine to rotate.



## Refrigerators

- A refrigerator is basically a heat engine in reverse. Work is done on a gas to move heat from a lower temperature reservoir to a high temperature reservoir.

## Thermodynamic efficiency

- Efficiency** (symbolized by  $\epsilon$ ) is a ratio of the work output to the work input. The more efficient a process is the closer the ratio is to 1. In thermodynamic processes, the energy available to perform work is  $Q_h$  (work input) and the work output =  $Q_h - Q_c$ .

$$\epsilon = \frac{W}{Q_h} = \frac{Q_h - Q_c}{Q_h} = 1 - \frac{Q_c}{Q_h}$$

- Find the efficiency of a gasoline engine that, during one cycle, receives 204 J of energy from combustion and loses 153 J as heat to the exhaust.

## Worksheet for practice problems on Ch. 10-11