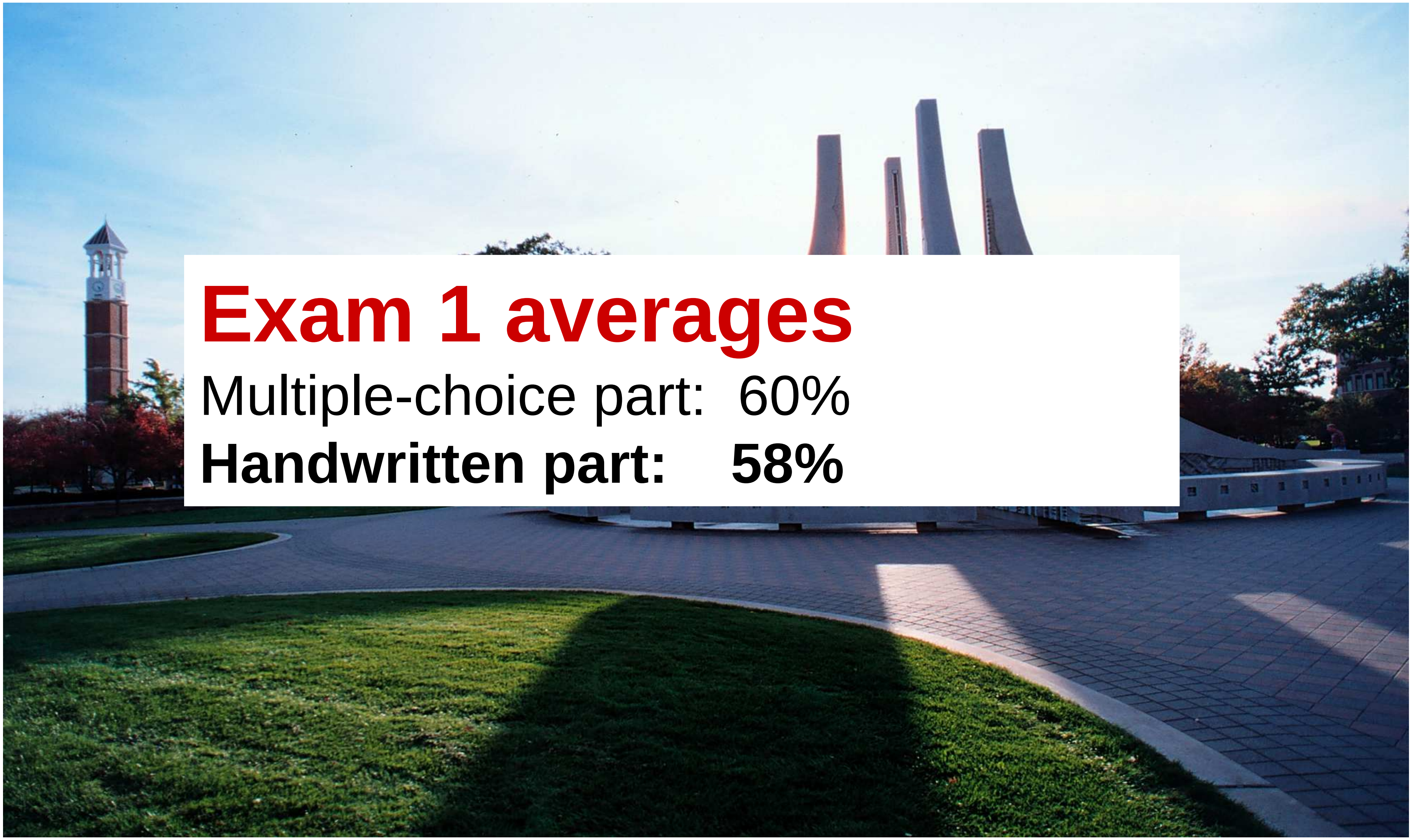


Exam 1 averages

Multiple-choice part: 60%

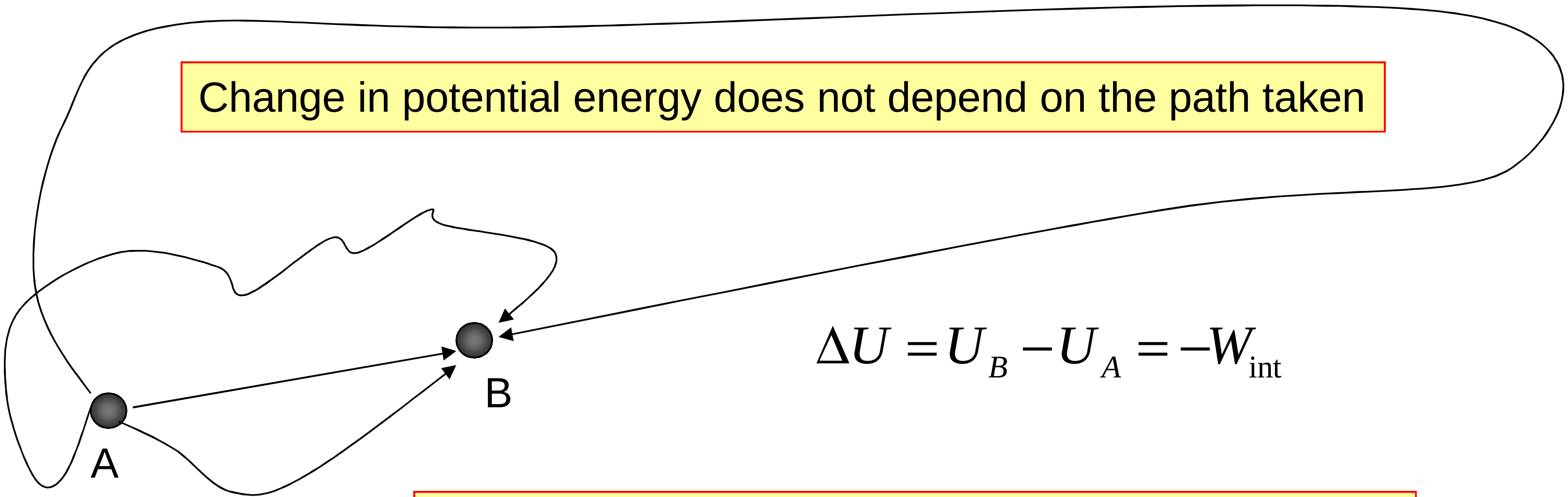
Handwritten part: 58%

TODAY

- Path-Independence of Potential Energy
- Temperature and Energy
- Heat Capacity
- Power
- Open and Closed Systems
- Volume and Temperature

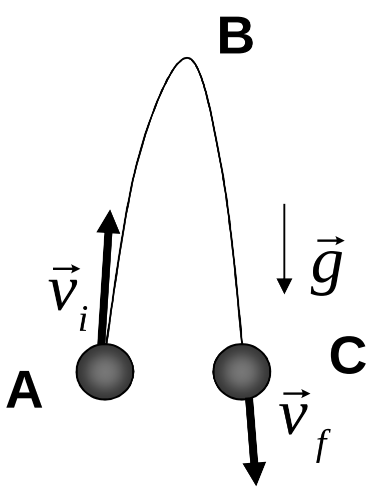
Path independence of potential energy

Change in potential energy does not depend on the path taken



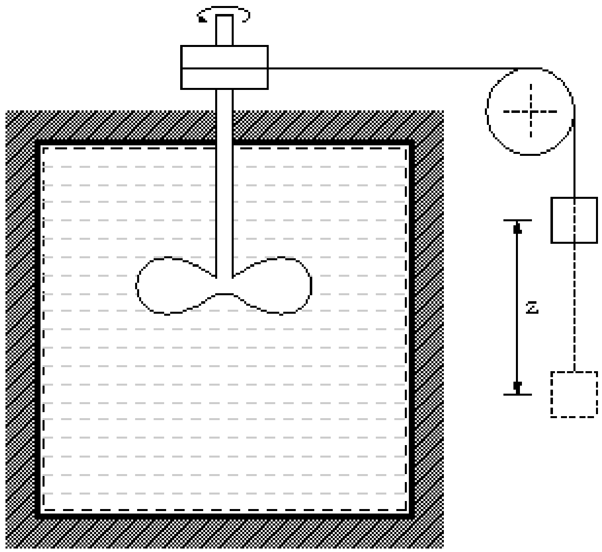
$$\Delta U = U_B - U_A = -W_{\text{int}}$$

In a round trip the potential energy does not change



At which point is the gravitational potential energy the largest?

Temperature and energy: the connection



Heat capacity:
amount of energy required to heat up a unit of mass by a unit of temperature

Specific heat capacity

Specific heat capacity *C*:
amount of energy required to heat up a unit of mass by a unit of temperature

$$\Delta E_{thermal} = Cm\Delta T$$

$$\boxed{C \equiv \frac{\Delta E_{thermal}}{m\Delta T}}$$

Usually expressed *per gram:*
J/(g·K)

Demo: fire syringe

Convert mechanical (kinetic) energy into heat

Example: heat capacity

Niagara Falls – what is the rise in water temperature due to gravity if there were no losses of energy?

Solution: $Cm\Delta T = mgh$

C_{water} = 4.186 J/(K·g)
h = 50 m

$$\Delta T = gh/C$$

$$= \frac{(9.8\ \mathrm{N/kg})(50\ \mathrm{m})}{(4.186\ \mathrm{J}/(\mathrm{K}\cdot\mathrm{g}))}$$

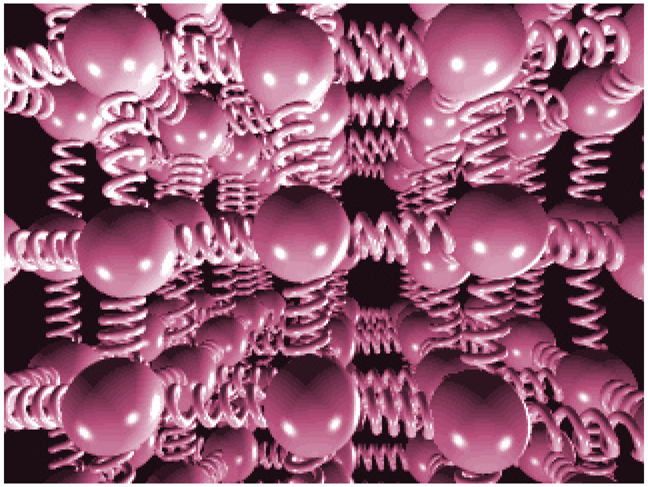
$$= 117\,\frac{\mathrm{N}\cdot\mathrm{m}\cdot\mathrm{K}\cdot\mathrm{g}}{\mathrm{J}\cdot\mathrm{kg}}$$

$$= 117\,\frac{\mathrm{N}\cdot\mathrm{m}\cdot\mathrm{K}\cdot\mathrm{g}}{\mathrm{N}\cdot\mathrm{m}\cdot\mathrm{kg}}$$

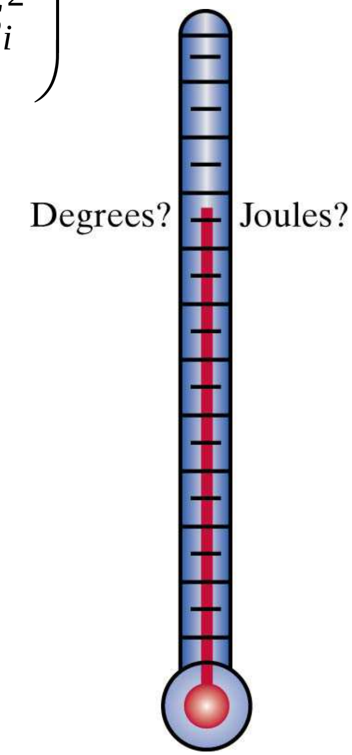
$$= 117\,\frac{\mathrm{K}\cdot\mathrm{g}}{1000\ \mathrm{g}}$$

$$= 0.117\ \mathrm{K}$$

Thermal energy



$$E = \sum_i \left(m_i c^2 + \frac{m_i v_i^2}{2} + \frac{1}{2} k_{s,i} s_i^2 \right)$$



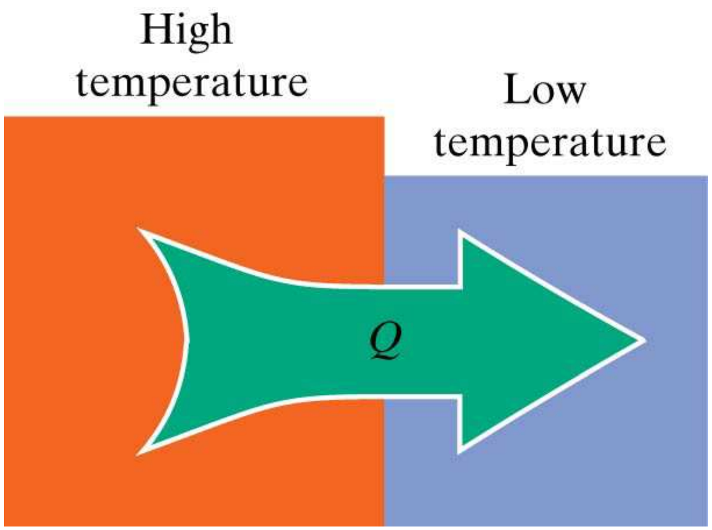
Sum over every atom!

1° K ≈ 10^{-23} J/molecule

Thermal energy transfer:

Thermal transfer of energy

A process in which energy moves between a system and surroundings with which it is in contact, due to a temperature difference



$$\Delta E_{sys} = Q + W$$

Work done on the system

Heat transferred to the system (microscopic work)

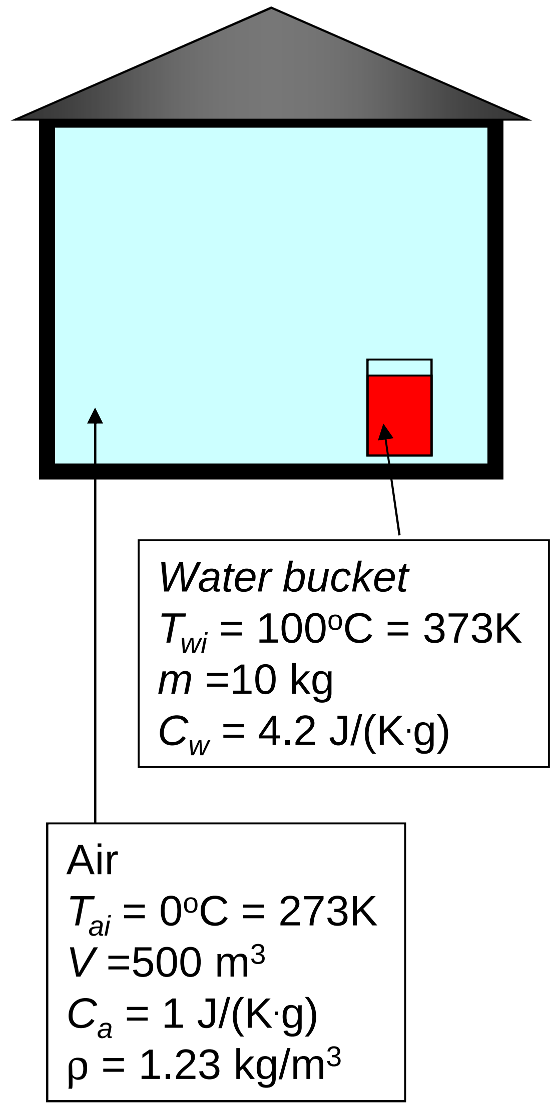
Reserve the word *heat* specifically to denote thermal energy transferred from one object to another

Flow of electromagnetic radiation can also change the energy

Sign of Q: "+" Transfer *into* system
"-" Transfer *out of* system

Example: heat

A perfectly insulated house has a volume of 500 m^3 (~1500 ft^2 house) and air temperature 0^{0}C. You bring in a closed bucket of water (10 L) of temperature 100^{0}C. What will the temperature be in the house after equilibration?



Solution: $$\Delta E_w + \Delta E_a = 0$$

$$C_w m_w \left(T_f - T_{wi}\right) + C_a m_a \left(T_f - T_{ai}\right) = 0$$

$$\left(C_w m_w + C_a m_a\right) T_f = C_w m_w T_{wi} + C_a m_a T_{ai}$$

$$T_f = \frac{C_w m_w T_{wi} + C_a m_a T_{ai}}{C_w m_w + C_a m_a} \qquad m_a = 615 \text{ kg}$$

$$T_f = 279.4 \text{ K} = 5.4\ ^{\text{o}}\text{C}$$

Ignored: walls, yourself, heat capacity dependence on T

Power (P)

Energy per unit time

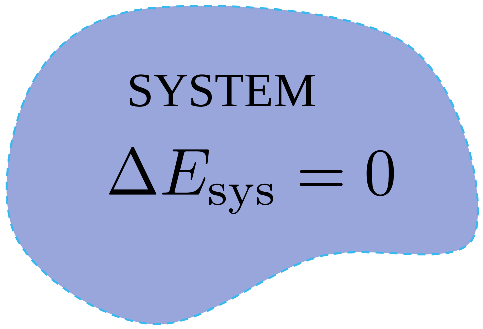
$$\boxed{P = \frac{dE}{dt}}$$

Unit: Watt, 1 W = 1 J/s

Power associated with work: $P = \frac{dW}{dt} = \frac{d\left(\vec{F}\cdot\vec{r}\right)}{dt} = \vec{F}\cdot\frac{d\vec{r}}{dt} = \vec{F}\cdot\vec{v}$

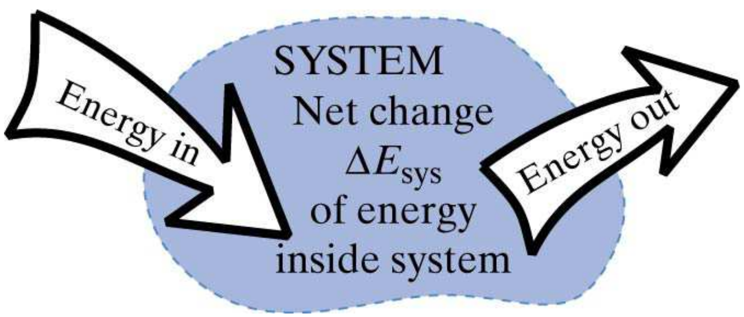
$$\boxed{P = \frac{dW}{dt} = \vec{F}\cdot\vec{v}}$$

Open and closed system



Closed system:
there is *no* energy flow between the system and surroundings

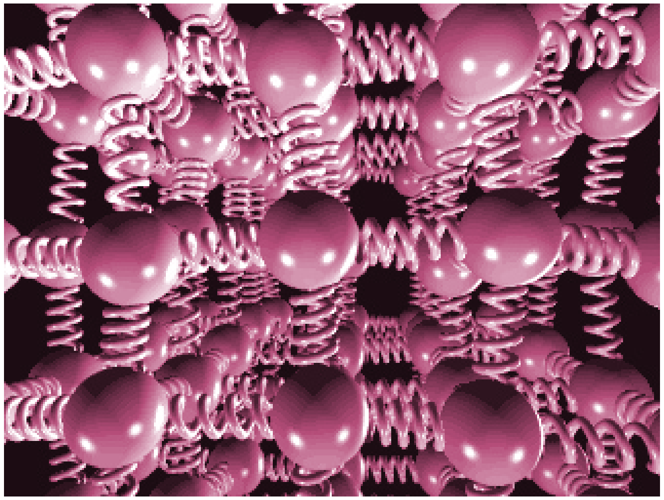
$$\Delta E_{\rm sys} = 0$$



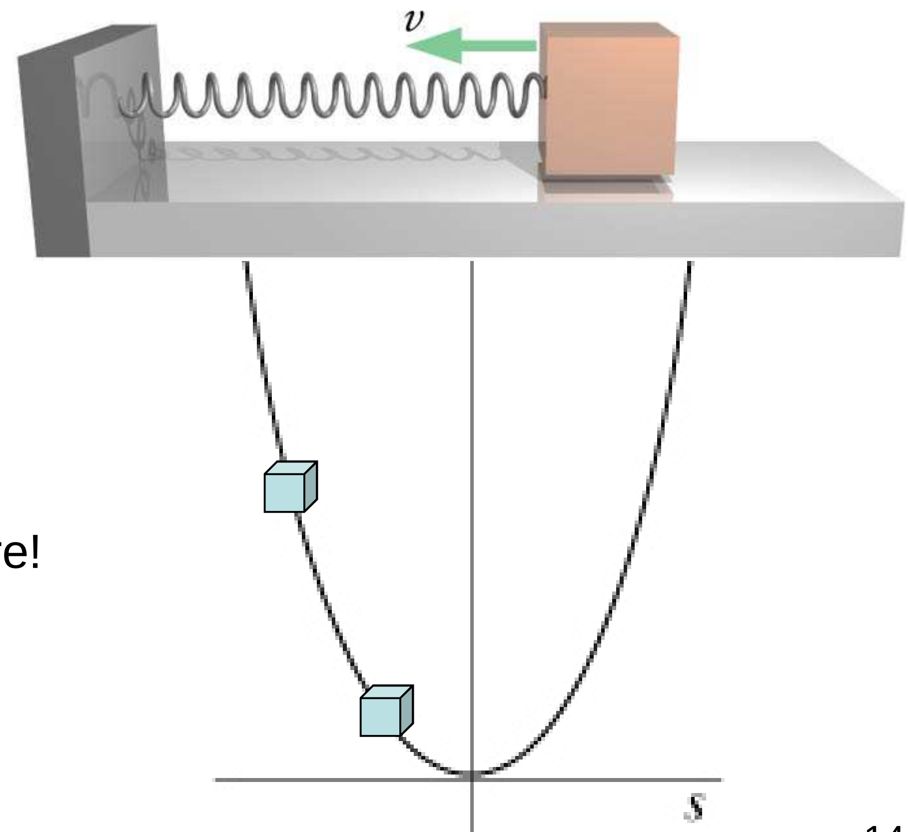
Open system:
there *is* energy flow between the system and surroundings

$$\Delta E_{\rm sys} \neq 0$$

Volume and temperature

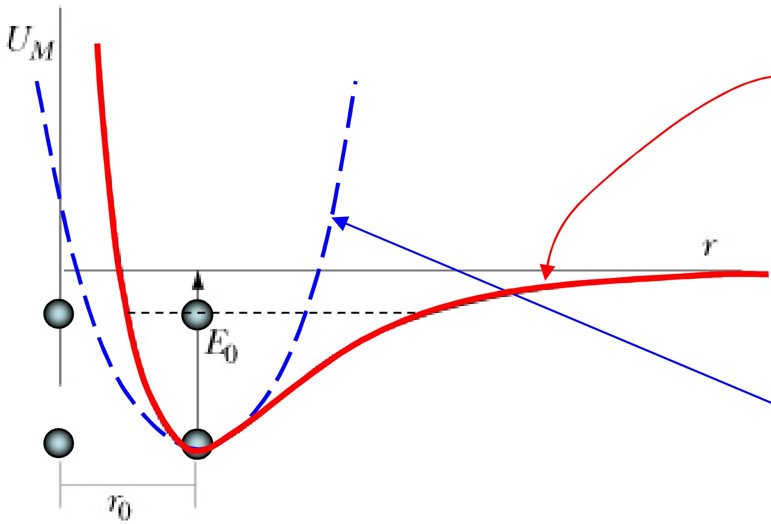


When energy rises the average distance between atoms in general must also increase leading to an increase in volume.



The spring law does not explain:
- volume changes with temperature!
- breaking

Interatomic **Morse** potential energy between two atoms

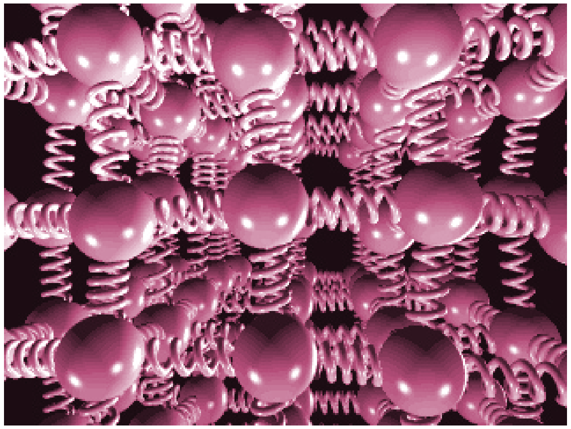


The **Morse potential** energy function is a realistic approximation

$$U_M = E_0\left[1 - e^{\alpha(r-r_0)}\right]^2 - E_0$$

Spring approximation:

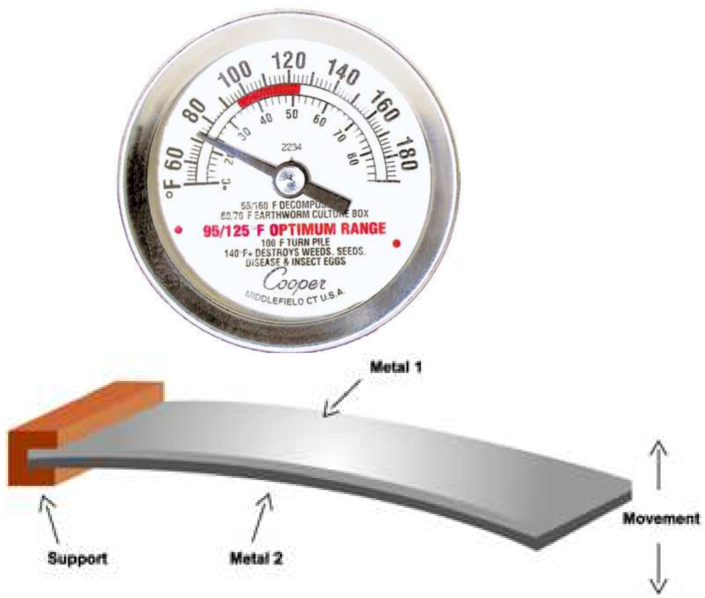
$$U_M \approx \frac{1}{2}k_s r^2 - E_0$$



When energy rises the average distance between atoms in general increases leading to increase in volume.

Thermometers based on expansion

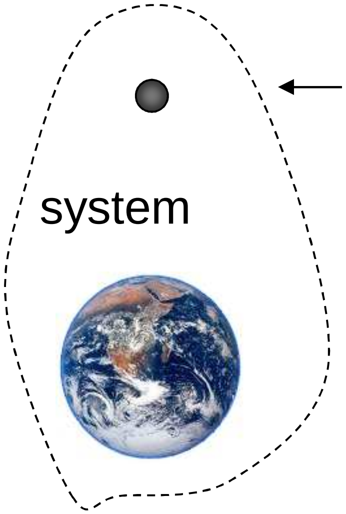
mercury



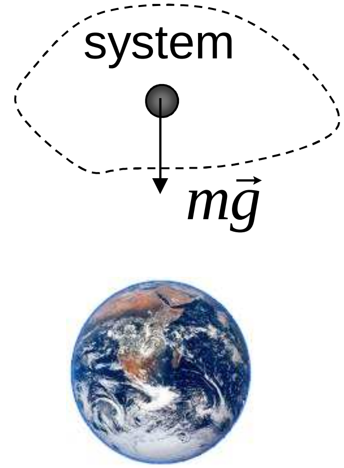
Bi-metallic

Galilean (buoyancy)

The choice of system and energy



Ball falls distance h toward Earth



Work!

$$\Delta E_{sys} = \Delta K + \Delta U_g = 0$$

$$\Delta K + (-mgh) = 0$$

$$\Delta E_{sys} = \Delta K = +mgh$$

HOME READING: 7.9

Analyze this statement:
"The Earth exerts a force *mg* through a distance *h* and does work *mgh*, and there is also a decrease in the potential energy –*mgh*, so the kinetic energy increases by 2*mgh*".

$$\Delta E_{sys} = \Delta K + (-mgh) = +mgh$$

WRONG!

Avoid double counting!

WHAT WE DID TODAY

- Path-Independence of Potential Energy
- Temperature and Energy
- Heat Capacity
- Power
- Open and Closed Systems
- Volume and Temperature