- real solids
  - real solids contain atoms which interact with each other
  - ball and spring model
    - where the ball is the atom and the spring is the interatomic bond
    - and the force between atoms is spring force ($\vec{F}_s = -k_s\vec{s}$)
- spring potential energy
  - $U_s = \int -\vec{F}_s \cdot d\vec{s}$
  - $U_s = \frac{1}{2}k_s s^2 + C$
- energy of mass spring system
  - compressed spring expands
    - PE of spring decreases
    - KE of mass increases
  - stretched spring contracts
    - PE of spring decreases
    - KE of mass increases
- potential energy of real springs
  - in a real spring
    - wire of spring deforms if stretched beyond a point when $U_s \to 0$
    - coils touch each other if compressed beyond a point when $U_s \to +\infty$ (spring pushes out with infinite strength)
- at any instantaneous location of a moving atom, the diagram shows:
  - total energy, E = K + U, is the energy value of horizontal line representing atom
  - potential energy, U, is the magnitude of PE, |U|, read off by drawing vertical line through atom position to PE curve
  - kinetic energy, K, is the difference between total energy line and PE curve
- energy diagram interpretation: the total energy is represented by the thick horizontal line (y = -0.2 eV). what is the approximate value of the kinetic energy, K (K = ?), and the potential energy, U (r_1, -1.3 eV) , at location r_1?
  - K = 1.1 eV, U = -1.3 eV
- PE for a pair of neutral atoms
  - morse potential: $U_M(r) = E_M[1 - e^{-\alpha(r - r_{eq})}]^2$
- energy of a multiparticle system
  - point particle approximation
    - kinetic energy due to translation of center of mass where $K = \frac{1}{2}Mv^2$
    - fixed rest energy due to rest mass where $E_{rest} = Mc^2$

    - multi-particle system
    - total constituent internal energy includes potential energy of system, rotational energy of system, vibrational energy of system, and others where $U \approx \frac{1}{2} k_{spring} s^2$
- thermal energy
    - temperature is a measure of average random internal K + U energy (thermal energy) of a system
    - if atoms vibrate more vigorously
        - average kinetic and potential energy are higher
        - temperature are higher
- energy transfer due to temperature difference with surroundings
    - the one way a system's thermal energy can change if thermal energy increases, atoms vibrate with more energy.
        - average interatomic distance increases
        - volume increases: thermal expansion
    - examples of thermal expansion
        - thermometer: mercury expands further into tube
        - thermostats: biz-metallic strip is heated, top metal expands faster than bottom metal, and strip bends downwards
- specific heat
    - the amount by which the thermal energy, $\Delta E_{Thermal}$, of a substance must increase to raise the temperature of 1 gram of it by 1°C.
    - Q is the energy transfer due to the temp difference between the system and surroundings. it causes a change in thermal energy of the system
    - $\Delta E_{Thermal}$ increasing the temperature of m grams of substance through temperatures ΔT then, the specific heat is $C = \frac{\Delta E_{Thermal}}{m \Delta T}$
- predicting temperature rise: the specific heat of aluminum is about 0.90 J/g/$^\circ$C. The specific heat of iron is about 0.45 J/g/$^\circ$C. a certain amount of heat is provided to raise the temp of an aluminum block through 20°C. what is the approximate temperature rise of an iron block of identical mass if the same amount of heat is added to it?
    - $40^\circ C$
- energy transfer due to temperature difference
    - when a hot object is placed in contact with a colder object, Q flows from the hotter object to the colder object
    - incorporated into energy principle: $\Delta E_{sys} = Q + W_{ext}$
- problem: a device used to determine specific heat, C, of a liquid is shown. as a block mass, m, drops a height, h, at a steady speed, it turns the blades of a fan in an insulated container causing a liquid of mass, M, in the container to have a temperature change ΔT. Find C in terms of other quantities

- system: liquid, block, string
- surroundings: Earth(neglect air resistance, friction of pulley etc.)
- $\Delta E_{sys} = Q + W_{ext}$
- $Q = 0$ due to insulated container
- $MC\Delta T = \vec{F} \cdot \Delta\vec{r}$
- $MC\Delta T = mgh$
- $C = \frac{mgh}{M\Delta T}$

- adiabatic processes: Q =0
  - if no heat energy is added/removed from a system, work done by surroundings, changes internal energy of the system
    - $\Delta E_{sys} = Q + W_{ext} \rightarrow \Delta E_{sys} = W_{ext}$
  - temperature of system changes accordingly
    - $\Delta T = \frac{\Delta E_{sys}}{mC} \rightarrow \Delta T = \frac{W_{ext}}{mC}$
- example of adiabatic process
  - system: syringe and everything in it (air and flammable material)
  - when you push down quickly on the syringe
    - there is no time for heat to leave and $Q = 0$
    - $W_{ext} > 0 \rightarrow \Delta T = \frac{W_{ext}}{mC} > 0$
  - as evidence of ΔT the flammable material catches fire (an adiabatic process)
- power
  - power is the rate at which work is done on a system
    - $P = \frac{W_{surr}}{\Delta t}$
    - $W_{surr} = \vec{F} \cdot \Delta\vec{r}$
    - $\vec{v} = \frac{\Delta\vec{r}}{\Delta t}$
    - $P = \vec{F} \cdot \vec{v}$
- open and closed systems
  - open systems exchange energy with surroundings
    - $\Delta E_{sys} = E_{in} - E_{out}$
      - if $E_{in} > E_{out}$ then $\Delta E_{sys} > 0$
      - if $E_{in} < E_{out}$ then $\Delta E_{sys} < 0$
      - in general $\Delta E_{sys} \neq 0$
  - closed systems do not exchange energy with surroundings
    - $E_{in} = E_{out} = 0 \rightarrow \Delta E_{sys} = 0$
- problem: a perfectly insulated house has a volume of 500m^3 and air temperature 0°C. you bring in a closed bucket of water (10kg) of temperature almost 100°C. what will the temperature be in the house after equilibrium?
  - closed system: water and air

- $\Delta E_{sys} = 0 \rightarrow \Delta E_{water} + \Delta E_{air} = 0$
- $m_w c_w (T_f - T_{wi}) + m_a c_a (T_f - T_{ai}) = 0$
- $T_f = \frac{c_w m_w T_{wi} + c_a m_a T_{ai}}{c_w m_w + c_a m_a}$
- given:
  - $T_{wi} = 100^{\circ}C = 373K$
  - $m_w = 10kg$
  - $c_w = 4.2J/(kg^{\circ}C)$
  - $T_{ai} = 0^{\circ}C = 273K$
  - $V_a = 500m^3$
  - $\rho_a = 1.23kg/m3$
  - $m_w = \rho_a V_a = 615kg$
  - $c_w = 1.0J/(kg^{\circ}C)$
- $T_f = 279.4K$

- system and energy accounting: a woman lifts a barbell, mass m, starting from rest through height h by applying a constant upward vertical force F, such that the final speed of the barbell is v.
  - system: barbell and earth
  - surroundings: woman
  - $\Delta E_{sys} = Q + W_{surr}$
  - $\Delta E_{barbell} + \Delta E_{earth} = W_{woman}$
  - $(\frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2) + mg\Delta y = Fh$
  - $\frac{1}{2} m v_f^2 - 0 + mgh - 0 = Fh$
  - system: barbell
  - surroundings: earth and woman
  - $\Delta E_{sys} = Q + W_{surr}$
  - $\Delta E_{barbell} = W_{woman} + W_{earth}$
  - $\frac{1}{2} m v_f^2 - 0 = Fh + \vec{F} \cdot \Delta \vec{r}$
  - $\frac{1}{2} m v_f^2 = Fh + \langle 0, -mg, 0 \rangle \cdot \langle 0, h, 0 \rangle$
  - $\frac{1}{2} m v_f^2 = Fh + -mgh$
- summary
  - from the energy diagram of a pair of neutral atoms one can determine the total energy, potential energy, and kinetic energy of the moving atom
  - energy of a multi-particle system: kinetic energy, rest mass energy, and internal energy
  - energy principle: $\Delta E_{sys} = Q + W_{ext}$
  - Sign of heat energy:
    - Q > 0 Energy flows from the surroundings to the system

    - Q < 0 Energy flows from the system to the surroundings
    - Q = 0 Adiabatic process where no energy flows between system and surroundings
- change in temperature of a system: $\Delta T = \frac{\Delta E_{sys}}{mC}$
    - c is the specific heat capacity of the system
- energy principle revisited: $\Delta K + \Delta U + \Delta E_{internal} = Q + W_{ext}$
    - where $E_{internal} = E_{rotation} + E_{vibration} + E_{thermal} + Others$
    -