- energy dissipation
  - total energy of the universe is conserved
    - but energy can be dissipated to less useful forms
  - examples
    - sliding friction
    - air resistance
  - in case of dissipation, energy of motion
    - is transferred to microscopic energy of molecules in contact with moving object
    - causes an increase in temperature of the objects in contact with each other
- air resistance
  - negligible for small dense object and falling a short distance
  - momentum principle
    - system: coin
    - surroundings: earth and air
    - $\frac{d\vec{p}_{sys}}{dt} = \vec{F}_{ext}$
    - $\frac{d\vec{p}_{coin}}{dt} = \vec{F}_g + \vec{F}_{air}$
    - $\vec{F}_{air} = 0$
    - $m\frac{d}{dt}\vec{v}_{coin} \approx \langle 0, -mg, 0\rangle$
    - $\frac{d}{dt}\vec{v}_{coin} \approx -g\hat{y}$
  - energy principle
    - system: coin and earth
    - surroundings: air
    - $\Delta E_{sys} = W_{surr}$
    - $\Delta K_{coin} + \Delta K_E + \Delta U_{int} = \vec{F}_{air} \cdot \Delta\vec{r}$
    - $\Delta K_E = 0$
    - $\vec{F}_{air} = 0$
    - $(\frac{1}{2}mv_{coin}^2 - 0) + (0 - mgh) \approx 0$
    - $v_{coin} \approx \sqrt{2gh}$
  - not negligible for large light objects and falling a long distance
  - momentum principle
    - system: filter
    - surroundings: earth and air
    - $\frac{d\vec{p}_{sys}}{dt} = \vec{F}_{ext}$
    - $\frac{d\vec{p}_{filter}}{dt} = \vec{F}_g + \vec{F}_{air}$

        - $\vec{F}_{air} = 0$
        - $\frac{d}{dt}\langle 0, mv_{filter}, 0\rangle \approx \langle 0, f - mg, 0\rangle$
        - $\frac{d}{dt}\vec{v}_{filter} \approx -(g - \frac{f}{m})\hat{y}$
    - energy principle
        - system: filter and earth
        - surroundings: air
        - $\Delta E_{sys} = W_{surr}$
        - $\Delta K_{filter} + \Delta K_E + \Delta U_{int} = W_{air}$
        - $\vec{F}_{air} = 0$
        - $(\frac{1}{2}mv_{filter}^2 - 0) + (0 - mgh) \approx C$
        - $v_{filter} \approx \sqrt{2gh + \frac{2W_{air}}{m}}$
        - W_{air} is negative
    - previously $\vec{F}_{air} = f\hat{y}$
        - but air drag is not constant
        - $\vec{F}_{air} \approx \frac{1}{2}C\rho Av^2(-\hat{v})$
        - drag coefficient: $0.3 \geq C \geq 1.0$
    - air resistance (drag) increases as square of velocity
    - so when velocity reaches a particular value
        - air drag = force due to gravity
        - $|\vec{F}_{air}| = |\vec{F}_g|$
        - $\vec{F}_{net} = 0$
        - velocity does not change: terminal velocity
- terminal velocity
    - $|\vec{F}_{air}| = |\vec{F}_g|$
    - $\frac{1}{2}C\rho Av^2 = mg$
    - $v_t = \sqrt{\frac{2mg}{C\rho A}}$
- viscous friction
    - proportional to velocity
    - mass-spring system
        - force due to spring
        - force due to viscous friction
        - damped oscillations
        - exponentially decreasing amplitude
    - momentum principle
        - $\frac{d\vec{p}}{dt} = \vec{F}_{spring} + \vec{F}_{viscous\ friction}$
- resonance

    - $x(t) = Ae^{-(\frac{c}{2m})t} cos(\omega_F t)$
    - $\omega_F = \sqrt{\frac{k_s}{m} - (\frac{c}{2m})^2}$
    - resonance occurs when the frequency of the driver, ω_D, equals the free oscillation frequency, ω_F: $\omega_D = \omega_F$
    - when this happens, the amplitude, A of the oscillation increases dramatically
- resonance in nature
    - different bonds of CO_2 have different resonant frequencies
- problem: a 1.0g coffee filter dropped from a height of 0.5m reaches a terminal speed of 1 m/s. how much KE approximately did the air molecules gain from the falling coffee filter? acceleration due to gravity is 10 m/s^2
    - system: filter and earth
    - air
    - $\Delta K + \Delta U = W_{surr}$
    - $(\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2) + (0 - mgh) = W_{surr}$
    - $W_{surr} = \Delta K_{air}$
    - ΔK_{air} = 0.5 x 10^{-3} - 5 x 10^{-3} = -4.5 x 10^{-3} J
- problem: a sky diver, mass 90 kg, reaches a terminal velocity of 60 m/s. what is the approximate magnitude of the force of the air resistance?
    - terminal velocity means $|\vec{F}_{air}| = |\vec{F}_g|$
    - $|\vec{F}_{air}| = mg = 90kg * 10m/s^2 = 900N$
- problem: when you drop a single coffee filter it reaches terminal speed, v_T, when magnitude of the drag force on it is F_d. If you were to now drop 4 identical filters (fitting snugly one inside the other), what would the new terminal speed and air drag force at this speed respectively be?
    - $2v_T, 4F_d$
    - $v_t = \sqrt{\frac{2mg}{C\rho A}}$
- problem: in the equation of position vs. time for a damped oscillator, what is the units of coefficient of viscous friction, c?
    - $\frac{kg}{s}$