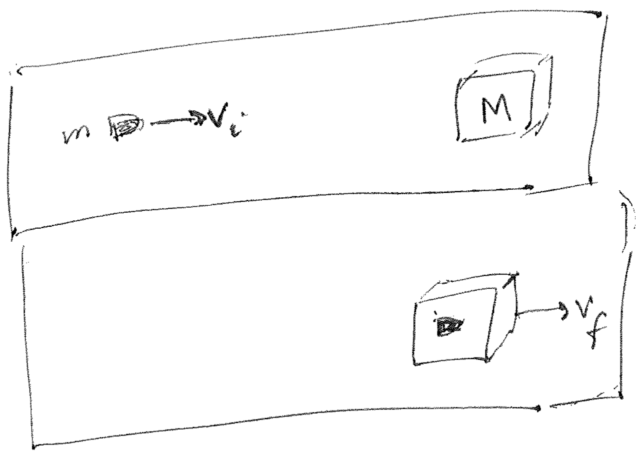
Collision between a bullet and a block



Q: What is conserved in this process?

A. momentum
B. mechanical energy
C. neither
D. both

[momentarily isolated ⟹ cons of mom]

$$mv_i + 0 = (M+m)v_f$$

$$v_f = \left(\frac{m}{M+m}\right)v_i$$

$$K_f = \frac{1}{2}(M+m)v_f^2 = \frac{1}{2}(M+m)\left(\frac{m}{M+m}\right)^2 v_i^2$$

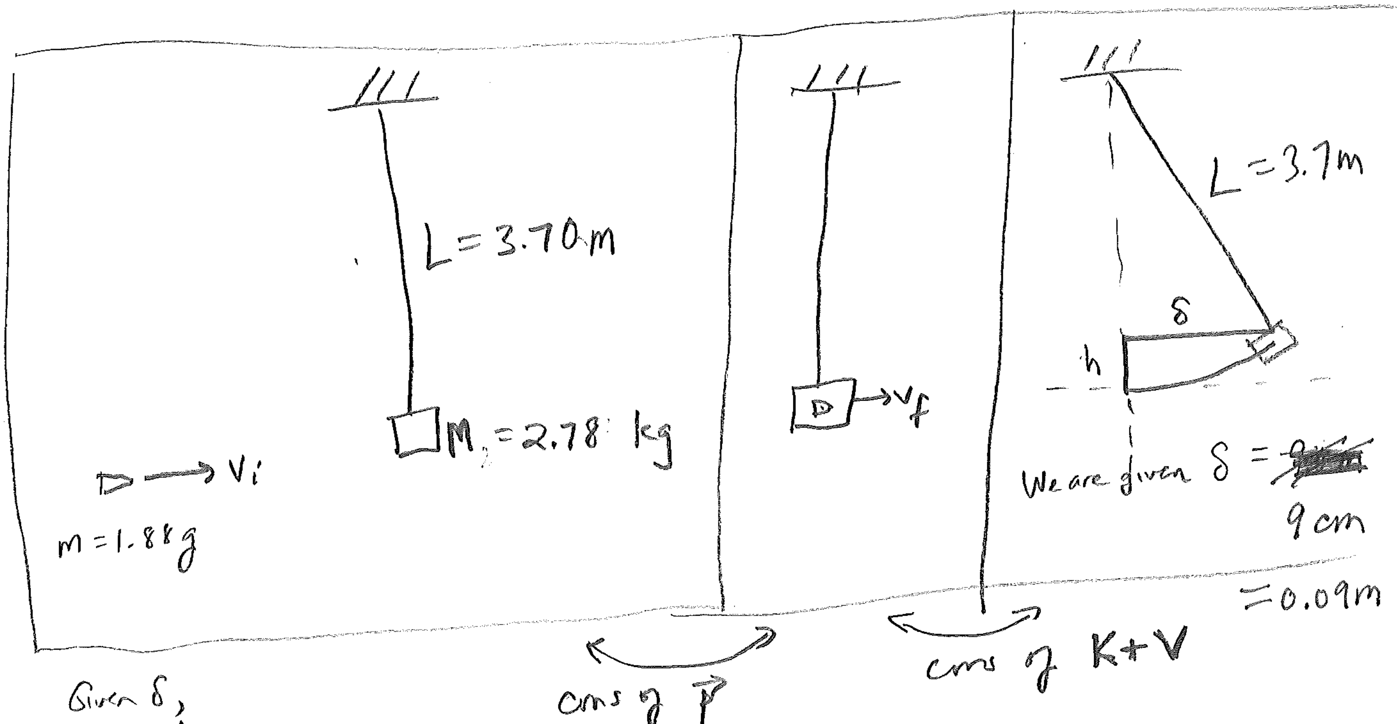
$$= \left(\frac{m}{M+m}\right)\frac{1}{2}mv_i^2 = \left(\frac{m}{M+m}\right)K_i$$

Mechanical energy of an isolated system is conserved if nonconservative forces do no work.

[normal force stopping the bullet] $\vec{v}$ $\vec{F}_N$

[Discuss lab expt.]

Ballistic pendulum: used to measure speed of a bullet.



Given δ,
M+m
~~Calc speed of bullet~~

~~step 1~~

$$\cancel{m v_i + M(0) = (M+m) v_f}$$

$$\cancel{v_i = \left(\frac{M+m}{m}\right) v_f \approx 1480\, v_f}$$

~~Completely inelastic so K is not conserved~~

step 2

$$\Delta K + \Delta V = 0$$

$$\left(0 - \tfrac{1}{2}(M+m)v_f^2\right) + (M+m)gh - 0 = 0$$

$$v_f = \sqrt{2gh}$$

$$h = L - \sqrt{L^2 - \delta^2} = 0.00109\ \text{m}$$

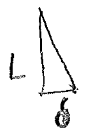
$$v_f = 0.146\ \text{m/s}$$

$$v_i = \frac{M+m}{m} v_f = 1480\, v_f = 217\ \text{m/s}$$

$$V_0 = \frac{m_{block}}{m_{bullet}}\sqrt{2gL(1-\cos\theta)} \approx \frac{m_{block}}{m_{bullet}}\sqrt{\cancel{2}gL\left(\frac{\delta}{L}\right)^2} = \frac{m_{block}\,\delta}{m_{bullet}}\sqrt{\frac{g}{L}}$$

Block = 2.784 kg

$$= (1480)(9\text{ cm})\sqrt{\frac{9.8\text{ m/s}^2}{3.7\text{ m}}} = \underline{217\ \frac{m}{s}}$$



in the plane of motion. The swinging radius, the r in Eq. 4.4, is the distance from the ceiling to the <u>top</u> of the pendulum. The distance from the ceiling to the <u>top</u> of the <u>bench</u> is 3.70 meters.

C. Amplitude indicator. The amplitude indicator is a small, metal rod that is inserted into a metal tube. As the block swings back, it pushes the rod into the tube. Then by knowing the initial distance from the block to the tube and by measuring the length of the rod extending, the displacement, d, is obtained. The pendulum will swing back about 9 cm. Good experimental technique suggest that the indicator rod should be placed so that it will move only a few cm. (Why?)

2. <u>Procedure</u>: Used a bolted down 22 Y load bullets - -

(a) Since the range must be kept clear during the firing, you should make the necessary preparations as promptly as possible, in particular, the suspension for the pendulum and the amplitude indicator. Some measurements, such as the swinging radius, r, can be made later.

There is some variation in the bullets, and, of course, there are other sources of variation. By using three to five shots, you should have enough indication of the range of values expected and enough information to compute the effective velocity of the bullet. The manufacturer gives the mass of the bullet as 1.88 gms, and the other information is directly measured. Compute v for <u>each</u> measurement and then compute an average v.

(b) For one specific measurement, compute (without an error range) the following:

1. The momentum of the bullet before impact.
2. The momentum of the block after impact.
3. The kinetic energy of the bullet before impact.
4. The kinetic energy of the block after impact.

Is there much difference between the energies? How do you account for this difference?

(c) The variation in your measurements of v does not take into account the systematic errors. The calculations are highly idealized--friction in the suspension and other energy losses are ignored--so we would expect the true value for v to be consistently different from the measured value. Let us try to estimate the order of magnitude of these errors.

One systematic error is the error in d due to the frictional losses of the swinging pendulum. Set the pendulum in the plane of motion. The swinging radius, the r in Eq. 4.4, is the distance from the ceiling to the top of the pendulum. The distance from the ceiling to the top of the bench is 3.70 meters.

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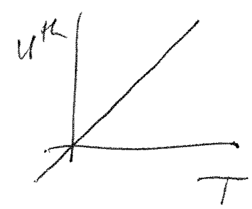
[where does excess kinetic energy go? thermal energy]

U^{th} = Thermal energy = microscopic kinetic energy

$$K^{sys} = \frac{1}{2} M v_{cm}^2 + \sum \frac{1}{2} m_j v_j'^2$$

$$\vec{v}_j' = \vec{v}_j - \vec{v}_{cm}$$

Thermal energy is measured by the temperature



For a monatomic ideal gas $U^{th} = \left(\frac{3}{2} k_B T\right) N$

k_B = Boltzmann const $= 1.38 \times 10^{-23}\ \frac{J}{K}$

T = temp (in Kelvin) $\rightarrow$

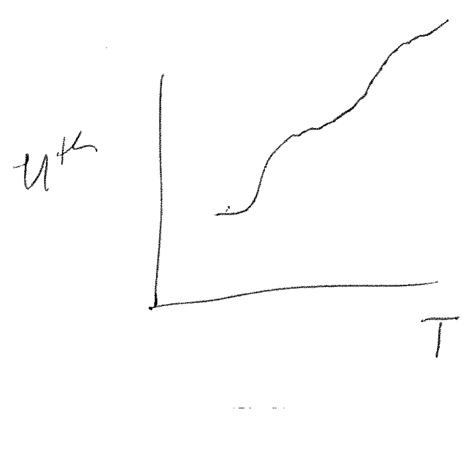
N = # atoms

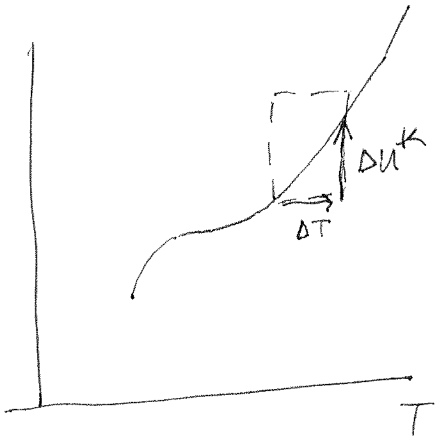
[C10.T3]

$0°C = 273.15\,K$

$T = 0 \Rightarrow U^{th} = 0$ ie no kinetic motion

~~For~~ more general substance, U^{th} is a complicated function T





If change in temperature is small (enough), U^{th} can be treated as linear

$$\Delta U^{th} = (\text{Const})\ \Delta T$$

$\uparrow$ slope of graph

Const depends on material and on mass m

c = specific heat

$$\Delta U^{th} = m c\ \Delta T$$

Then conservation of energy $\Rightarrow$ $\Delta K + \Delta V + \Delta U^{th} = 0$

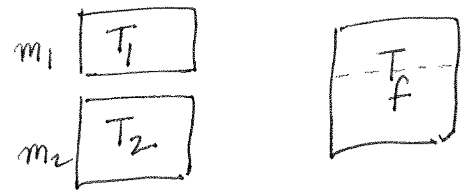
[eg. can use this to calc ΔT of bullet]

Water: $c = \dfrac{1\ \text{cal}}{g \cdot {}^\circ C} = \dfrac{4.186\ J}{(10^{-3}\,kg)\ K} = 4186\ \dfrac{J}{kg\text{-}K}$

Ice $\sim \dfrac{2100\ J}{kg\text{-}K}$

(1 food calorie = 1 kcal = 4186 J)

[Can also use conservation of energy to determine final temperature of 2 substances mixed together]



← thermal equilibrium (all at same temp)

$$0 = \Delta U_1^{th} + \Delta U_2^{th}$$ (if system is "thermally insulated")

$$= c_1 m_1 \Delta T_1 + c_2 m_2 \Delta T_2$$

$$= c_1 m_1 (T_f - T_1) + c_2 m_2 (T_f - T_2)$$

$$\Rightarrow T_f = \frac{c_1 m_1 T + c_2 m_2 T_2}{c_1 m_1 + c_2 m_2}$$

[C10.T7]

[C10.T8] same

$\frac{1}{2}(1000)(23)^2 = 265\ J$

$(3.8kg)(15C)(4186) = 240\ J$

[Add milk before or after it cools, if want it to cool down faster?]

Add milk first

$T_f = f T_m + (1-f) T_w$ $\quad$ f = fraction of milk in tea

~~Then it cools to half~~ $\cancel{\Rightarrow \left(\frac{T_f - T_a}{2}\right) + T_a = \frac{T_f + T_a}{2}}$

$(T_f - T_a)e + T_a$

~~T_a = ambient temp~~

~~so~~ $\cancel{\frac{f T_m + (1-f) T_w + T_a}{2}}$

$[f T_m + (1-f) T_w - T_a]e + T_a$

Instead let cool ~~to half~~

$\cancel{T_w \to \left(\frac{T_w + T_a}{2}\right)} \to [T_w - T_a]e + T_a$

then add milk

$\cancel{T = f T_m + (1-f)\left(\frac{T_w + T_a}{2}\right)}$

$\cancel{= \frac{(1-f)}{2} T_w + \frac{T_a}{2} + f\frac{T_m}{2} + f\frac{T_m}{2} - \frac{f}{2} T_a}$

$\to f T_m + (1-f)[(T_w - T_a)e + T_a]$

$\cancel{= (1-f) T_w e - T_a e}$

diff:

$f T_m (1-e) + f T_a e - f T_a = f(T_m - T_a)(1-e)$

C10T.1 A railroad car collides with a similar car at rest. The cars lock togther. Does this process convert a significant amount of energy to thermal energy (compared to the first car's kinetic energy)?
A. No.
B. Yes.
C. We need more information to be sure.

C10T.2 The *root-mean-square* (rms) speed of a molecule's motion is the speed that the molecule would have if its actual kinetic energy were equal to its average kinetic energy K_{avg}. The rms speed of random motion of a nitrogen molecule in a container of air at room temperature is about 510 m/s. The mass of a hydrogen molecule is about 14 times smaller. What is *its* rms speed of random motion at the same temperature? Select the closest response.
A. 35 m/s
B. 140 m/s
C. 510 m/s
D. 1910 m/s
E. 7100 m/s

C10T.3 Say that the rms speed of random motion of helium gas molecules at room temperature (22°C) is v. If the temperature "doubles" (to 44°C), what is this speed now? Select the closest response. (*Hint:* Why the quotation marks?)
A. About the same
B. $\sqrt{2}v$
C. $2v$
D. $4v$

C10T.4 If you rub your hands together, they get warmer (try it!). Rubbing therefore heats your hands, true (T) or false (F)?

C10T.5 Is the change in the following objects' thermal energies due to a flow of heat (A) or work (B)?

a. A hot cup of tea on a table becomes cooler with time.
b. A meteorite entering the atmosphere glows white-hot.
c. Liquid nitrogen poured on a slab of ice boils furiously. (Liquid nitrogen boils at 77 K.)
d. A drill bit gets hot as it drills a hole in a metal slab.

C10T.6 The specific "heat" of water is roughly constant (within 0.2%) over a range from 5°C to 95°C, but changes significantly near its freezing and boiling points. Considering this, a change in temperature from 373 K to 373.5 K will likely be "sufficiently small" that one can use equation C10.7 to calculate accurately the thermal energy change of a certain amount of water, T or F?

C10T.7 Objects A and B are made of the same substance, but object A is twice as massive as B. Originally, object A has a temperature of 100°C, and B has a temperature of 0°C. If these objects are placed in contact, they will eventually come to a common final temperature T_f. Assuming that these objects are isolated from everything else, what is the value of T_f?

A. $T_f = 100°C$
B. $T_f > 50°C$
C. $T_f = 50°C$
D. $T_f < 50°C$
E. $T_f = 0°C$

C10T.8 Which describes the relationship between the energy E_A required to increase a 1000-kg car's speed from 0 to 23 m/s (about 50 mi/h) and the energy E_B required to increase the temperature of 1 gal ($\approx$ 3.8 kg) of lemonade from refrigerator temperature ($\approx$ 5°C) to room temperature?

A. $E_A \gg E_B$
B. $E_B \gg E_A$
C. $E_A \approx E_B$