Things you must know:

Definition of average velocity

Definition of momentum

The Momentum Principle

Other physical quantities:

$$\gamma \equiv \frac{1}{\sqrt{1-\left(\frac{|\vec{v}|}{c}\right)^2}}$$

$$\vec{F}_{grav} = -G\frac{m_1 m_2}{|\vec{r}|^2}\hat{r}$$

$\left|\vec{F}_{grav}\right| \approx mg$ near Earth's surface

$$\vec{F}_{elec} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{|\vec{r}|^2}\hat{r}$$

$\left|\vec{F}_{spring}\right| = k_s s$ opposite to the stretch

$\hat{f} = \langle \cos\theta_x, \cos\theta_y, \cos\theta_z \rangle$ unit vector from angles

Constant	Symbol	Approximate Value
Speed of light	c	3×10^{8} m/s
Gravitational constant	G	6.7×10^{-11} N · m^2/kg^2
Approx. grav field near Earth's surface	g	9.8 N/kg
Electron mass	m_e	9×10^{-31} kg
Proton mass	m_p	1.7×10^{-27} kg
Neutron mass	m_n	1.7×10^{-27} kg
Electric constant	$\frac{1}{4\pi\epsilon_0}$	9×10^{9} N · m^2/C^2
Proton charge	e	1.6×10^{-19} C
Avogadro's number	N_A	6.02×10^{23} atoms/mol

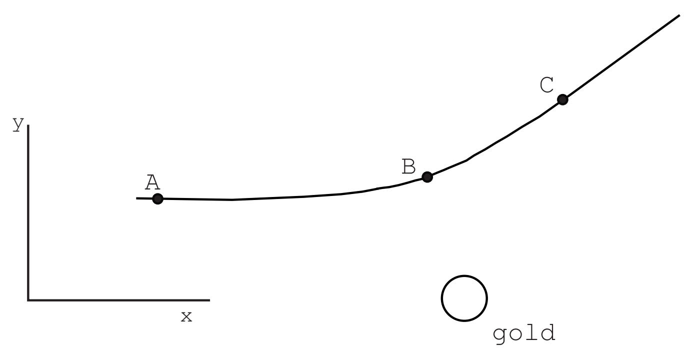
milli	m	1×10^{-3}	kilo	K	1×10^{3}
micro	μ	1×10^{-6}	mega	M	1×10^{6}
nano	n	1×10^{-9}	giga	G	1×10^{9}
pico	p	1×10^{-12}	tera	T	1×10^{12}

Problem 1

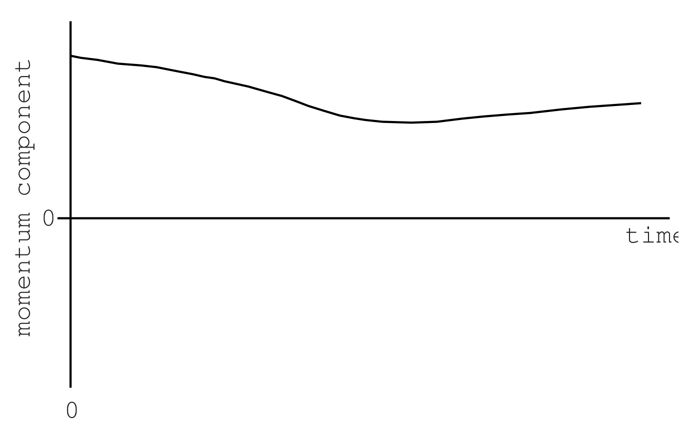
A block of steel with mass 2.8 kg sits on a low-friction surface. A bullet of mass 70 grams traveling horizontally with speed 280 m/s bounces straight back from the block with speed 200 m/s.
(a) What is the speed of the block of steel just after the collision?
(b) What is the increase $\Delta E_{\text{thermal}}$ in the thermal energy of the block and bullet?

Problem 2)

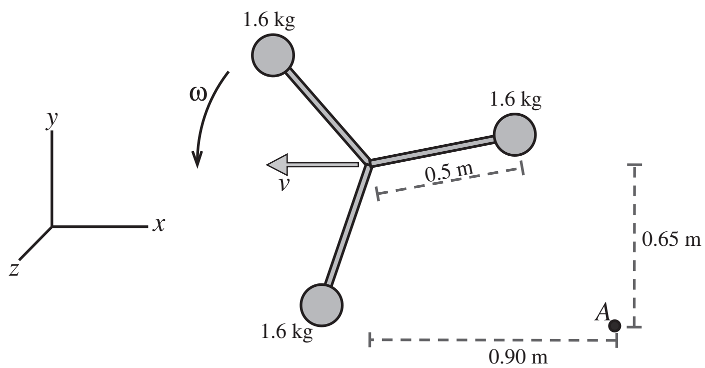
An alpha particle (a helium nucleus: two protons and two neutrons) passes near the nucleus of a gold atom, which is initially at rest. The alpha particle travels from location A to location B to location C along the path shown in the diagram below.



1. At each location marked by a letter draw *and label* an arrow representing the momentum of the alpha particle. Make sure the direction of the arrow is correct, and the relative lengths of the arrows are correct (that is, larger magnitude is indicated by an arrow that is clearly longer).
2. At each location marked by a letter draw *and label* an arrow representing the electric force exerted on the alpha particle by the gold nucleus. As above, make sure direction and relative magnitude are clear, and that your arrows are labeled.
3. The graph below shows one component of the alpha particle's momentum as a function of time during this encounter. Is this the x-component or the y-component of the alpha particle's momentum? Explain briefly how you can tell.
4. On the graph below, draw a graph showing the same component (x or y) of the momentum of the gold nucleus, as a function of time, and label your graph.



Problem 3



The device in the diagram consists of three identical 1.6 kg masses, each connected to the center of the device by a 0.50 m long lightweight rod. The device is in outer space, and its center of mass is moving with a velocity $\vec{v} = \langle -6.80, 0, 0\rangle$ m/s, while the barbell rotates about its center of mass at $\omega = 12.5$ rad/sec in the counter-clockwise direction.

1. What is the total kinetic energy of the barbell?

   A. 111.0 J B. 93.8 J C. 204.7 J
   D. 37.0 J E. 68.2 J

2. What is the translational angular momentum of the barbell with respect to location A in the diagram?

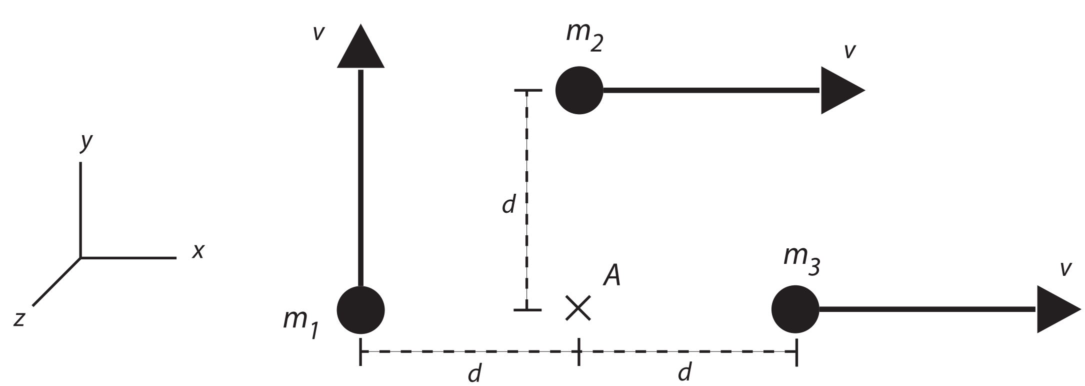
   A. $\langle 0, 0, 15.0\rangle$ kg m^2/s B. $\langle -29.4, 0, 0\rangle$ kg m^2/s C. $\langle 0, 0, 29.4\rangle$ kg m^2/s
   D. $\langle 0, 0, 21.2\rangle$ kg m^2/s E. $\langle -21.2, 0, 0\rangle$ kg m^2/s

3. What is the rotational angular momentum of the barbell with respect to its center of mass?

   A. $\langle 0, 0, -15.0\rangle$ kg m^2/s B. $\langle 0, 0, 15.0\rangle$ kg m^2/s C. $\langle 0, 0, -93.8\rangle$ kg m^2/s
   D. $\langle 0, 0, 93.8\rangle$ kg m^2/s E. $\langle 0, 0, 21.2\rangle$ kg m^2/s

Problem 4

Three spherical masses, m_1, m_2, and m_3 are moving as shown in the diagram. Each mass is 3 kg. Each has a speed $v = 15$ m/s, and the center of each is a distance $d = 2$ m from location A in the diagram.



1. What is the direction of the angular momentum of mass m_1 about location A?

   Circle your choice: **+x** **-x** **+y** **-y** **+z** **-z** **zero**

2. What is the direction of the angular momentum of mass m_2 about location A?

   Circle your choice: **+x** **-x** **+y** **-y** **+z** **-z** **zero**

3. What is the direction of the angular momentum of mass m_3 about location A?

   Circle your choice: **+x** **-x** **+y** **-y** **+z** **-z** **zero**

4. Calculate the magnitude of the angular momentum of mass m_1 about location A. If it is zero, say so explicitly.

Problem 5
List all the possible ways of arranging 3 quanta of energy among 4 oscillators.

Problem 6
Particle A consists of 4 aluminum atoms and initially has 1 quantum of energy.
Particle B consists of 2 aluminum atoms and initially has 2 quanta of energy.
The two particles are brought in contact with each other. (The mass of one mole of aluminum is 27 grams.)
(a) Using the Einstein model of a solid, calculate and plot $\ln\Omega_A$, $\ln\Omega_B$, and $\ln\Omega_{\text{total}}$ vs. q_A (the number of quanta in particle A). Put all three plots on the same graph, and label them. Show your work and explain briefly.

(b) Indicate the point of thermal equilibrium on your graph of $\ln\Omega_A$, $\ln\Omega_B$, and $\ln\Omega_{\text{total}}$. Calculate the approximate temperature of particle A at this point. State what assumptions or approximations you made.

Problem 7 A nearly reversible engine is used to melt ice as well as do some useful work. If the engine does 1000 J of work and dumps 400 J into ice, what is the temperature of the hot source?