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

Definitions and Specific Results

Projectile Motion: $x_f = x_i + v_{xi}\Delta t$ $\quad y_f = y_i + v_{yi}\Delta t - \frac{1}{2}g(\Delta t)^2$ $\quad v_{xf} = v_{xi}$ $\quad v_{yf} = v_{yi} - g\Delta t$

$\vec{F}_{\text{elec on 2 by 1}} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{|\vec{r}|^2}\hat{r}$ $\quad \vec{F}_{\text{grav on 2 by 1}} = -G\frac{m_1 m_2}{|\vec{r}|^2}\hat{r}$ $\quad \left|\vec{F}_{\text{grav}}\right| \approx mg$ near Earth's surface

$U_{\text{elec}} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{|\vec{r}|}$ $\quad U_{\text{grav}} = -G\frac{m_1 m_2}{|\vec{r}|}$ $\quad U_{\text{grav}} \approx mgy$ near Earth's surface

$\left|\vec{F}_{\text{spring}}\right| = k_s|s|$ $\quad U_{spring} = \frac{1}{2}k_s s^2$ $\quad \Delta E_{thermal} = mC\Delta T$

$\vec{F}_{air} \approx -\frac{1}{2}C\rho A v^2\hat{v}$ $\quad \left|\vec{F}_{buoyancy}\right| =$ weight of displaced fluid

$K \approx \frac{1}{2}mv^2 = \frac{p^2}{2m}$ for $v << c$ $\quad E^2 - (pc)^2 = (mc^2)^2$ $\quad W = \vec{F}\cdot\Delta\vec{r}_{point.of.application}$

$Y = \frac{F_T/A}{\Delta L/L}$ (macro) $\quad Y = \frac{k_{s,i}}{d}$ (micro) $\quad v = d\sqrt{\frac{k_{s,i}}{m_a}}$

$\vec{F}_{\parallel} = \frac{d|\vec{p}|}{dt}\hat{p}$ $\quad \vec{F}_{\perp} = |p|\frac{d\hat{p}}{dt} = -|p|\frac{m|v|}{r}\hat{r}$

$x(t) = A\cos(\omega t)$ $\quad \omega = \sqrt{\frac{k_s}{m}}$ $\quad T = \frac{2\pi}{\omega}$

$\vec{L}_A = \vec{r}_A \times \vec{p}$ $\quad \vec{\tau}_A = \vec{r}_A \times \vec{F}$ $\quad \left|\vec{A}\times\vec{B}\right| = AB\sin\theta_{AB} = A_\perp B$

Multiparticle Systems: $\vec{r}_{cm} = \frac{m_1\vec{r}_1 + m_1\vec{r}_1 + \ldots}{m_1 + m_2 + \ldots}$ $\quad \vec{P}_{tot} \approx M\vec{v}_{cm}$ (v<<c)

$K_{tot} = K_{trans} + K_{rel}$ $\quad K_{trans} \approx \frac{1}{2}Mv_{cm}^2$ (v<<c) $\quad K_{rel} = K_{rot} + K_{vib}$ $\quad K_{rot} = \frac{1}{2}I\omega^2$

$\vec{L}_{tot.A} = \vec{L}_{trans.A} + \vec{L}_{rot.cm}$ $\quad \vec{L}_{trans.A} = \vec{r}_{cm\leftarrow A}\times\vec{P}_{tot}$ $\quad \vec{L}_{rot.cm} = I\vec{\omega}$ $\quad I = m_1 r_{1\perp cm}^2 + m_2 r_{2\perp cm}^2 + \ldots$

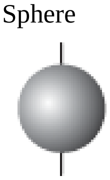
Physical Constants

$c = 3\times10^8$ m/s $\quad e = 1.6\times10^{-19}$ C $\quad N_A = 6.02\times10^{23}$ atoms/mole

$g = 9.8$ m/s^2 $\quad G = 6.7\times10^{-11}\,\text{N}\cdot\text{m}^2/\text{kg}^2$ $\quad 1/4\pi\varepsilon_0 = 9\times10^9\,\text{N}\cdot\text{m}^2/\text{C}^2$

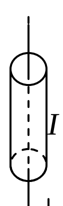
$m_{\text{proton}} = 1.7\times10^{-27}$ kg $\quad m_{\text{electron}} = 9\times10^{-31}$ kg $\quad 1\text{ eV} = 1.6\times10^{-19}$ J

Sphere



$I = \frac{2}{5}MR^2$

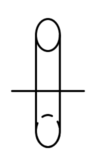
Cylinder or disk



$I = \frac{1}{2}MR^2$

R

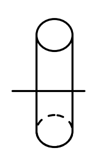
Thin rod (about axis shown)



L

$I = \frac{1}{12}ML^2$

Solid cylinder (about axis shown)



L

$I = \frac{1}{12}ML^2 + \frac{1}{4}MR^2$

1. What are the three *fundamental principles* that were covered in this course? Express them in equations with correct notation and in words (just a sentence or two). (7 pts.)

   (a) Name:

   Equation:

   (b) Name:

   Equation:

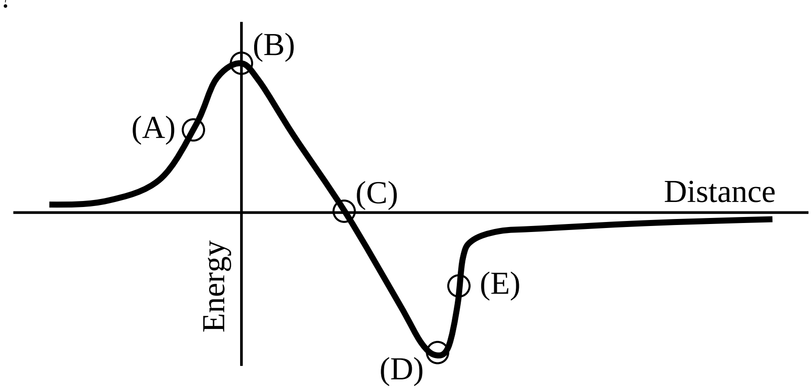
   (c) Name:

   Equation:

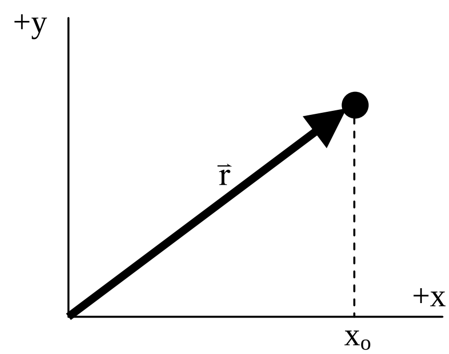
   (d) What is the single idea that these three principles quantify?

Multiple Choice: (Circle the *best* answer. No explanation required.) (28 pts)

2. **(2pts)** Where on the following *potential energy* diagram is the magnitude of the force the largest?

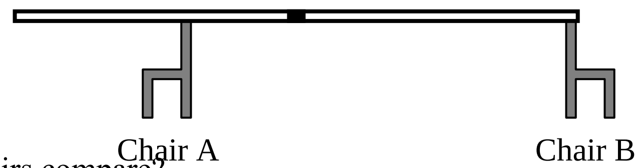


3. **(2pts)** A ball is thrown straight up into the air without spin from point x_o. The diagram at the right shows the position vector $\vec{r}$ while the ball is on the way up. While the ball is <u>on the way up</u>, what is the direction of the ball's angular momentum relative to the origin?



   (a) Down (–y)
   (b) Up (+y)
   (c) Out of the page (+z)
   (d) Into the page (–z)
   (e) There is no angular momentum because the ball is not rotating around the origin.

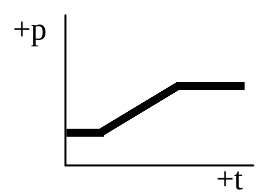
4. **(2pts)** A uniform plank is supported by the backs of two chairs, as shown on the diagram to the right. The center of mass of the plank is marked. How do the magnitudes of the <u>torques</u> exerted by the chairs compare?

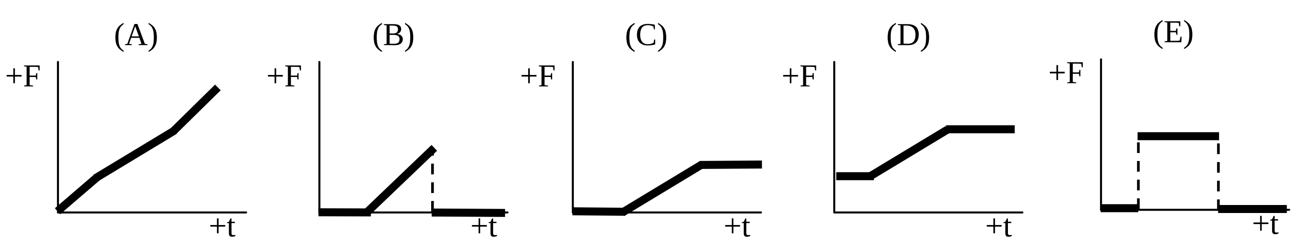


   (a) Chair A exerts a greater torque about the center of the plank than Chair B.
   (b) Both chairs exert the same magnitude of torque about the center of the plank.
   (c) Chair B exerts a greater torque about the center of the plank than Chair A.
   (d) It is impossible to tell which torque is larger without knowing the magnitude of forces each chair exerts on the plank.
   (e) It is impossible to tell which torque is larger without knowing both the magnitude of the forces and the distance of each from the center of the plank.

5. **(2pts)** For the uniform plank supported by the backs of the two chairs described in problem 4, how do the magnitudes of the <u>forces</u> exerted by the chairs compare?
   (a) Chair A exerts a greater force than Chair B.
   (b) Both chairs exert equal forces.
   (c) Chair B exerts a greater force than Chair A.
   (d) It is impossible to tell which force is larger without knowing the weight of the plank.
   (e) It is impossible to tell which force is larger without knowing more about the chairs.

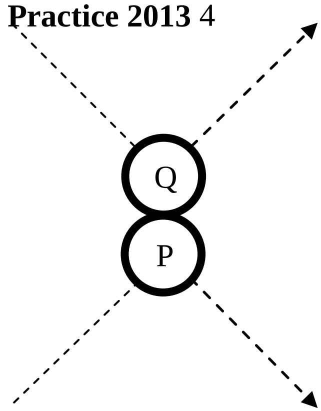
6. **(2pts)** The momentum of an object moving in one dimension as a function of time is shown in the graph at the right. Which graph below best represents the magnitude of the net-force versus time relationship for this object?





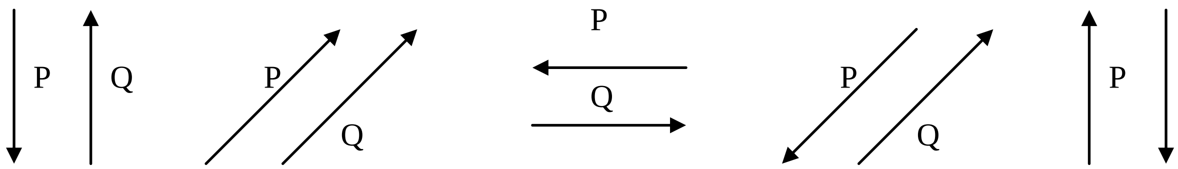
Refer to the following diagram when answering the next two questions.

This diagram depicts the paths of two colliding steel balls, P and Q



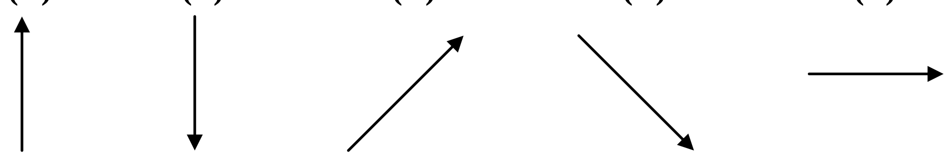
7. **(2pts)** Which set of arrows best represents the direction of the <u>change in momentum</u> of each ball?

(A) **(B)** **(C)** **(D)** **(E)**

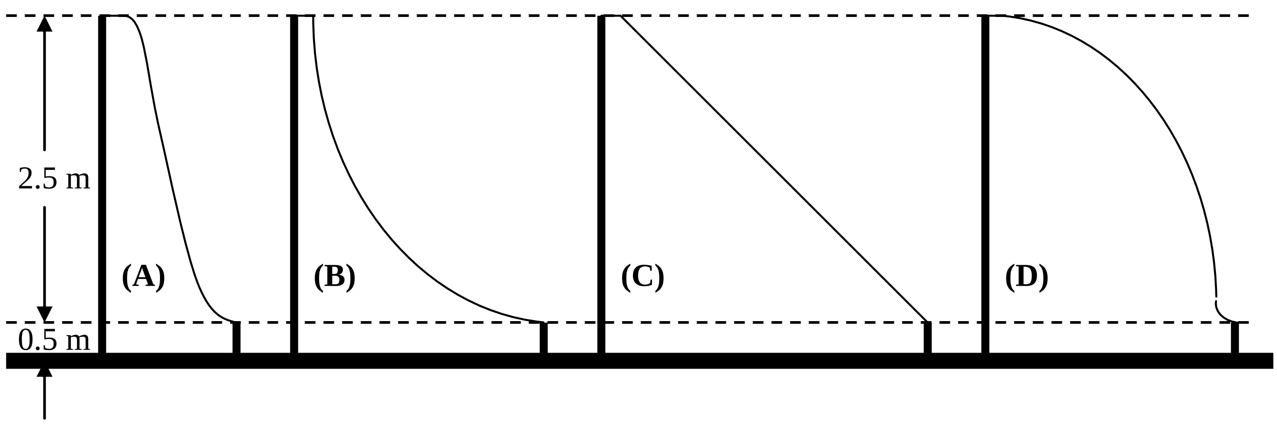


8. **(2pts)** Which arrow best represents the direction of the <u>Force</u> applied to ball Q by ball P during the collision?

(A) **(B)** **(C)** **(D)** **(E)**

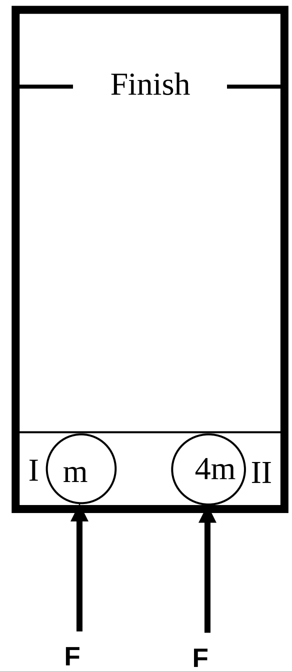


9. **(2pts)** A young girl wishes to select one of the <u>frictionless</u> playground slides illustrated below to give her the greatest possible speed when she reaches the bottom of the slide. Which one of the five choices should she choose?



(E) It doesn't matter. Her speed would be the same for each.

Refer to the following diagram to the right when answering the next three questions. This diagram depicts two pucks on a frictionless table. Puck II is four times as massive as puck I. Starting from rest, the pucks are pushed across the table by two equal forces.



10. **(2pts)** Which puck will have the greatest <u>kinetic energy</u> upon reaching the finish line?
    (a) I
    (b) II
    (c) They both have the same amount
    (d) Too little information to answer

11. **(2pts)** Which puck will reach the finish line first?
    (a) I
    (b) II
    (c) They both reach the finish line at the same time
    (d) Too little information to answer

12. **(2pts)** Which puck will have the greater <u>momentum</u> upon reaching the finish line?
    (a) I
    (b) II
    (c) They both have the same momentum
    (d) Too little information to answer

13. **(2pts)** A string is wrapped around a disk of mass M and radius R. Starting from rest, you pull the string with a constant force *F* along a nearly frictionless surface. At the instant when the center of the disk has moved a distance *d*, a length *L* has unwound off the disk. At this instant what is the speed of the center of mass of the disk?

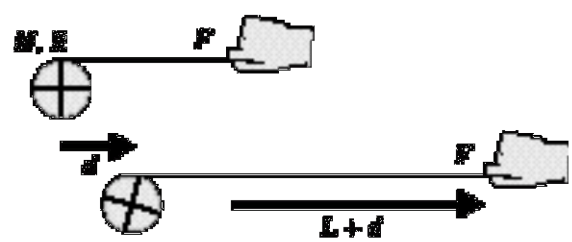
    (a) $v_{CM} = \sqrt{\frac{2F}{M}d}$

    (b) $v_{CM} = \sqrt{\frac{2F}{M}L}$

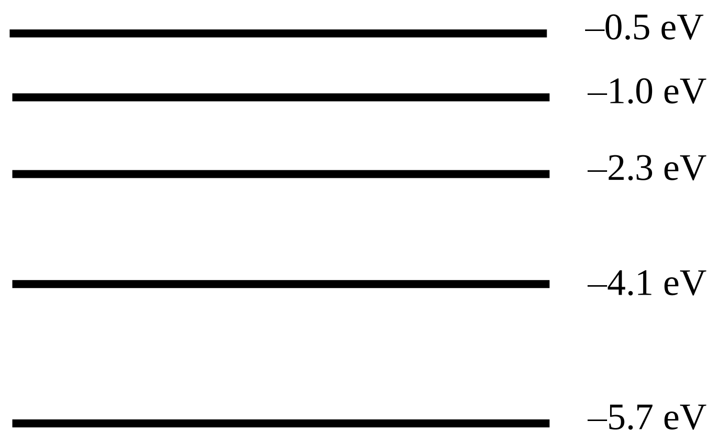
    (c) $v_{CM} = \sqrt{\frac{2F}{M}(L+d)}$

    (d) $v_{CM} = \sqrt{\frac{2F}{M}R}$

    (e) $v_{CM} = \sqrt{\frac{2F}{M}\frac{2\pi R}{d}L}$



Use the following energy level diagram for a particular atom when answering the



next two questions. Assume the atom only has these five energy levels.

14. **(2pts)** If the atom has a total energy (excluding rest mass) of –2.3 eV, what energy (or energies) of emitted photons are possible?
    (a) 2.3 eV.
    (b) –2.3 eV, –4.1 eV, –5.7 eV.
    (c) –2.3 eV, –1.0 eV, –0.5 eV.
    (d) 1.8 eV, 3.4 eV
    (e) 1.3 eV, 1.8 eV

15. **(2pts)** Suppose a broad spectrum of light is passed through a collection of these atoms at a low temperature. How many dark lines would there be in the absorption spectrum?
    (a) Less than 3
    (b) 3
    (c) 4
    (d) 5
    (e) More than 5

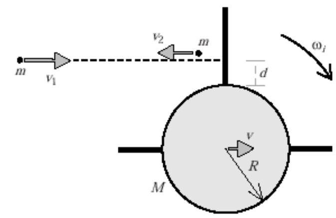
16. (**10 pts.**) A block of steel with mass 2.8 kg sits on a low-friction surface. A rubber bullet of mass 70 grams traveling horizontally with speed 280 m/s bounces straight back from the block with speed 200 m/s.

    (a) What is the speed of the block of steel just after the collision?

    (b) What is the total change in the thermal energy ($\Delta E_{\text{thermal}}$) of the block and bullet during the collision?

Problem 3 (30 pts)

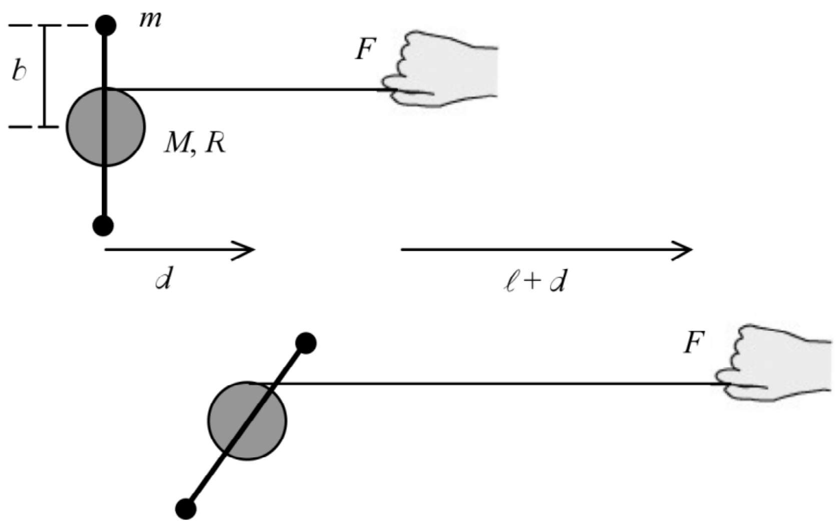
The space shuttle is approximately a uniform cylinder of mass M and radius R with low-mass wings and tail as shown. Originally it is traveling to the right with speed v and rotating clockwise with angular speed ω_i .
A tiny meteor of mass m traveling at speed v 1 hits the tail at a distance d from the outside of the shuttle body and bounces back at reduced speed v_2 .



(a) (15 pts) After the collision, the velocity of the center of mass of the shuttle is < v_x , v_y , 0 >. Calculate v_x and v_y . Show your work.

(b) (15 pts) After the collision, calculate the angular speed of the shuttle, ω_f . Show your work.

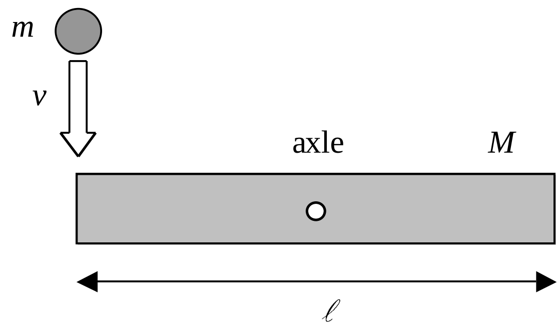
17. **(15 pts)** A string is wrapped around a uniform-density disk of mass M, radius R, and moment of inertia $\frac{1}{2}MR^2$. Attached to the disk are two low-mass rods, each with a small mass m at the end, a distance b from the center of the disk. The apparatus is initially at rest on a nearly frictionless surface. The string is pulled with a constant force F. At the instant when the center of the disk has moved a distance d, a length ℓ of string has unwound off the disk, so your hand has moved a distance $\ell + d$.



(a) At this instant, what is the speed v of the center of the apparatus? Explain your work.

(b) At this instant, what is the angular speed ω of the apparatus? Explain your work.

20. **(15 pts)** A beam of length ℓ and mass M is free to spin with very little friction on a vertical axis through its center. The beam is initially at rest. The moment of inertia of the beam is $\frac{1}{12}M\ell^2$ (note that the fraction is *not* one half). A ball of clay with a mass m is traveling horizontally at a speed of v just before it strikes and sticks to the end of the beam. The *top view* of the situation is shown below.



(a) The total kinetic energy of the beam and the clay before the collision is larger than the total kinetic energy afterwards. What happened to the energy? (1 pt)

(b) What its angular speed ω just after the collision (in terms of the quantities in the diagram)? Explain what system you choose to analyze and what principle(s) you use. (8 pts)

System=____ (1 pt)

Principle(s)=_____________________________________ (1 pt)

(c) Suppose that the beam has a mass of 1.5 kg and a length of 50 cm and the clay has a mass of 100 g and a speed of 4 m/s. What is the total kinetic energy of the beam and the clay after the collision? (7 pts)

Bonus: (5 pts) Briefly describe your favorite Exploring Physics reading. Why is this your favorite?