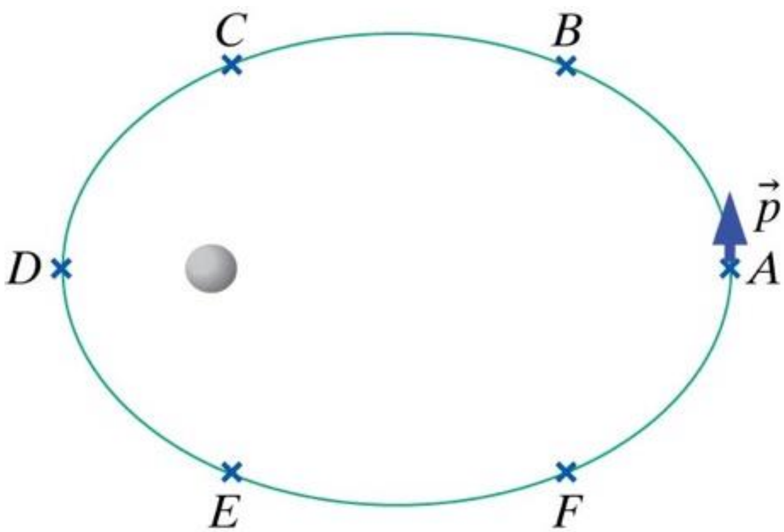
Problem 01: [8 points]

Starting from each of the locations, A-F, the comet advances in the next instant along its orbit. What is the sign of the work done on the comet by the star at different points in the orbit?



A) $W_A = W_D = 0; W_B, W_C < 0; W_E, W_F > 0$

B) $W_A = W_D = 0; W_B, W_C > 0; W_E, W_F < 0$

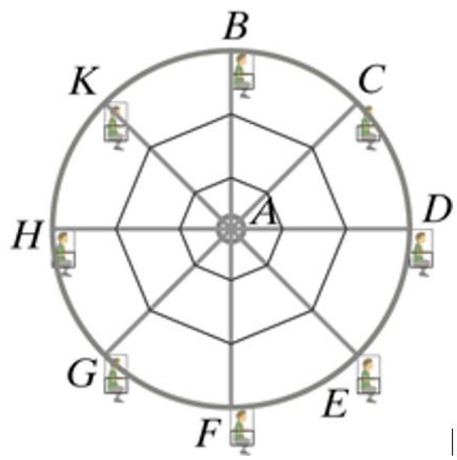
C) $W_A = W_C = W_D = W_E = 0; W_B, > 0; W_F < 0$

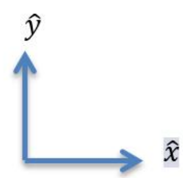
D) No work is done on the comet by the star

E) None of the above

Problem 02: [8 points]

A Ferris wheel is a vertical, circular amusement ride with radius, $R = \mathbf{10}\ m$. Riders sit on seats that swivel to remain horizontal. The Ferris wheel rotates so that riders move at a *constant* speed, $v = \mathbf{5}\ m/s$. Consider a rider whose mass, $m = \mathbf{60}\ kg$. Assume that the acceleration due to gravity, $g = \mathbf{10}\ m/s^2$.





How much **work** does the force exerted by the ***seat*** do on the rider as they move **from point *H* to point *B***?

A) $-600\ J$

B) $-6000\ J$

C) $600\ J$

D) $6000\ J$

E) None of the above, because the rider's speed does not change.

Problem 03: [8 points]

The program below calculates the motion of an object attached to a spring moving along an inclined ramp. What is the error in the code below?

```
GlowScript 3.1 VPython
m = 0.3
g = 9.81
L0 = 1.0
Li = 0.3
si = L0-Li
ks = 3.5

Ramp = box(pos=vec(0,-0.105,0), axis=vec(cos(0.262),sin(0.262),0),
          length=L0+si, height=0.01, width=0.2)

Spring = helix(axis=Ramp.axis, coils=10, radius=0.1, length = Li)
Spring.pos = vec(-0.5*Ramp.length*cos(0.262), -0.5*Ramp.length*sin(0.262), 0)

Ball = sphere(pos=Spring.pos + Li*Ramp.axis, radius=0.1, color=color.cyan)
Ball.mom = vec(0, 0, 0)

Fgrav = vec(0,-1*m*g,0)

FrampMag = m*g*cos(0.262)
Framp = FrampMag*vec(-1*sin(0.262),cos(0.262),0)

t = 0
dt = 0.02
T = 10
while (t < T):
    rate(100)
    Fspring = -1*ks*(Spring.length-L0)*Ramp.axis
    Fnet = Fspring + Fgrav
    Ball.mom = Ball.mom + Fnet*dt
    Ball.pos = Ball.pos + (Ball.mom/m)*dt
    t = t + dt
    Spring.length = mag(Ball.pos - Spring.pos)
```

A) The spring force is not correctly calculated.

B) The net force is not correctly calculated.

C) The gravitational force is not updated.

D) The spring length is not correctly updated.

E) The ball momentum is not correctly updated.

Problem 04: [8 points]

A space craft, mass $100\ kg$ is in outer space at location $< 1, 2, 5 >\ m$ moving at an initial speed of $2\ m/s$ One set of thrusters are now turned on and exert a constant force $< -100, 200, 0 >\ N$ until the object reaches location $< 2, 3, 5 >\ m$. At this point, these thrusters are turned off, and another set of thrusters are turned on which exert a constant force $< 200\ \ -100, 0 >\ N$ until the space craft reaches $< 5, 4, 5 >\ m$.

What is the speed of the space craft at the final location?

A) 4.00 m/s

B) 2.00 m/s

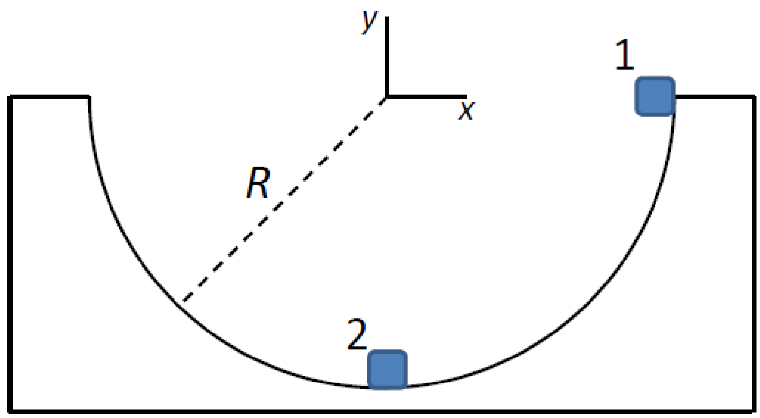
C) 8.00 m/s

D) 16.0 m/s

E) None of the above

Problem 05-06

An ice block of mass m is initially at rest at location 1 on a smooth semicircular track in a vertical plane. A little later it is sliding through location 2.



Problem 05: [4 points]

What is the speed, v of the ice block at location 2?

A) $v = \sqrt{gR}$
B) $v = \sqrt{2gR}$
C) $v = \sqrt{3gR}$
D) $v = 2\sqrt{gR}$
E) None of the above

Problem 06: [4 points]

What is the magnitude of the normal force, F_N exerted on the block by the ice surface at point 2?

A) $F_N = mg$
B) $F_N = 2mg$
C) $F_N = 3mg$
D) $F_N = 4mg$
E) None of the above

Problem 07: [8 points]

A radioactive nucleus of mass M_1 is at rest when it decays into an alpha particle (He-4 nucleus), mass M_α, and a new nucleus, mass M_2. When the alpha particle and the new nucleus have moved far away from each other (so that the electric potential energy of the final alpha-nucleus system is negligible),

Which of the following represents the sum of the kinetic energies of the alpha particle and the new nucleus?

A) M_1c^2

B) $M_2c^2 + M_\alpha c^2$

C) $M_2c^2 - M_\alpha c^2$

D) $M_1c^2 - M_2c^2 - M_\alpha c^2$

E) $M_1c^2 + M_2c^2 + M_\alpha c^2$

Problem 08: [8 points]

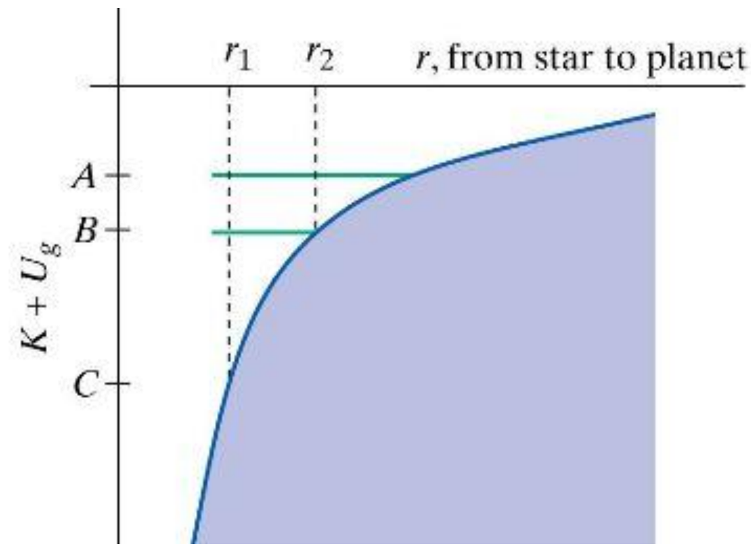
The figure below is a graph of the energy of a system consisting of a planet interacting with a star.

The gravitational potential energy U is shown as the thick curve.

The thick horizontal lines represent $K + U$.

Suppose that when distance from the star to the planet is r_1, $K + U = A$

Find ALL of the TRUE statements from among statements 1 through 5 below.



1. K *decreases* as the distance from star to planet changes from r_1 to r_2
2. K *increases* as the distance from star to planet changes from r_1 to r_2
3. When the distance from star to planet is r_2, $K = A - B$.
4. The system is a bound system; the planet can never escape.
5. When the distance from star to planet is r_1, $K = B - C$.

A) 1, 4, 5

B) 2, 3, 5

C) 1, 3, 4

D) 2, 3, 4

E) 1, 3, 5

Problem 09: [8 points]

Three protons, each of mass $\boldsymbol{m}$ and charge $+\boldsymbol{e}$, are initially held at the corners of a ***triangle*** that is $\boldsymbol{d}$ on a side. They are then released from rest.

Which of the following equations will you need to solve to determine the speed v of each proton, when the protons are very far apart?

A) $3\left(\frac{1}{2}mv^2\right) = 3\left(\frac{1}{4\pi\varepsilon_0}\frac{e^2}{d}\right)$

B) $3\left(\frac{1}{2}mv^2\right) = 2\left(\frac{1}{4\pi\varepsilon_0}\frac{e^2}{d}\right)$

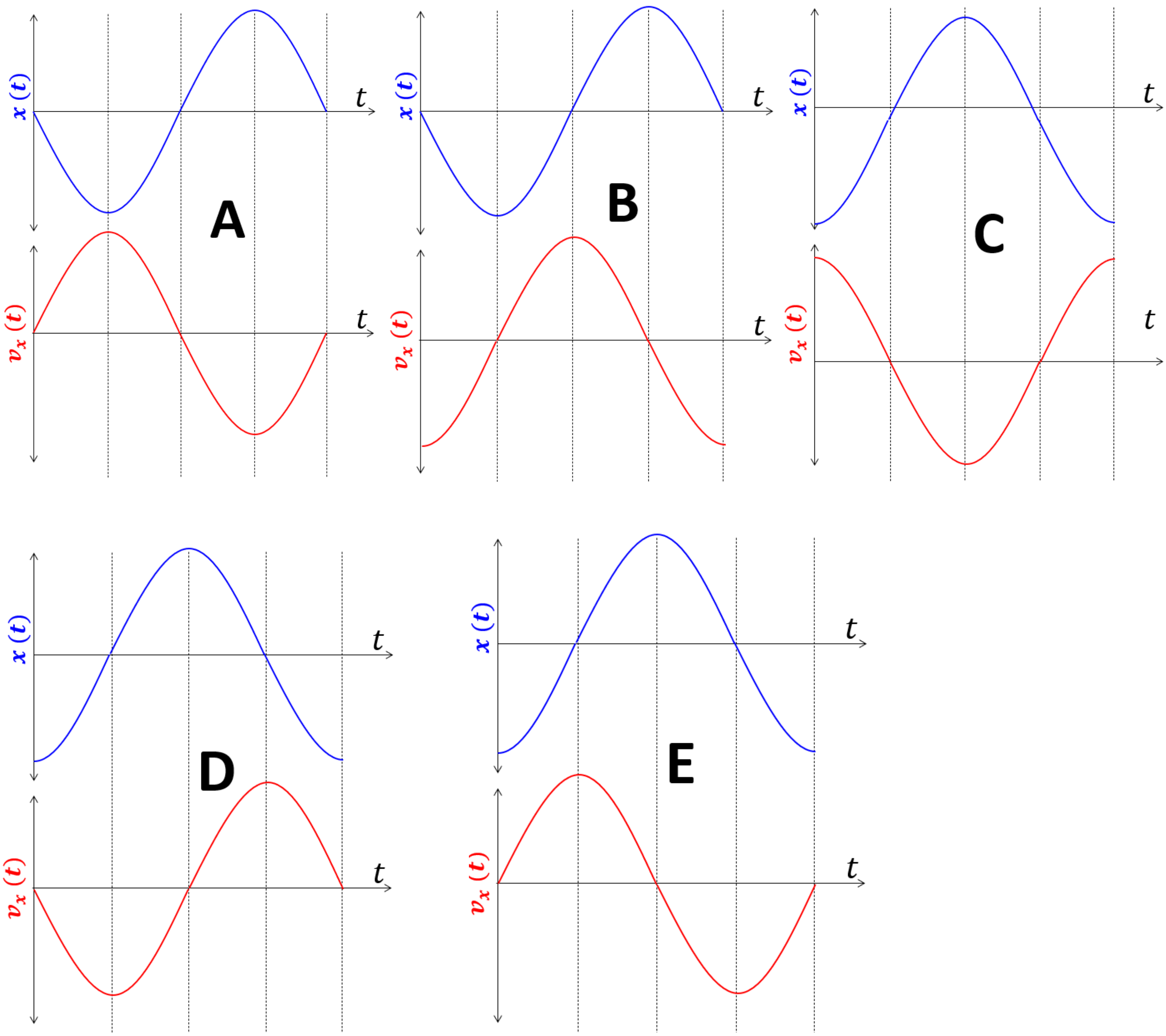
C) $\left(\frac{1}{2}mv^2\right) = 3\left(\frac{1}{4\pi\varepsilon_0}\frac{e^2}{d}\right)$

D) $2\left(\frac{1}{2}mv^2\right) = 3\left(\frac{1}{4\pi\varepsilon_0}\frac{e^2}{d}\right)$

E) None of the above

Problem 10: [8 points]

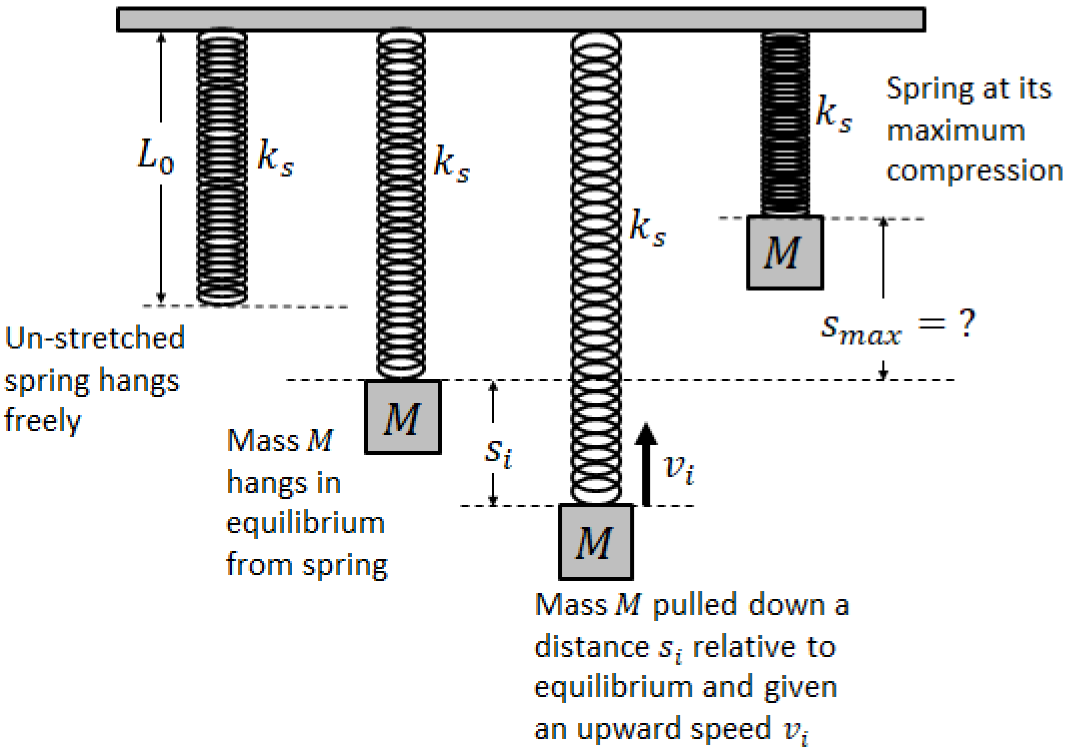
An object attached to a spring oscillates back and forth on an incline plane. The x-axis is parallel to the incline plane. The equilibrium position is $x = 0$, and the positive x-axis is in the direction of stretching. At $t = 0$, the object is released from the compressed spring position. Which graphs represents the position, $x(t)$ and velocity, $v_x(t)$ of the object?



Problem 11: [8 points]

A motionless light vertical hanging spring, stiffness constant $\boldsymbol{k_s}$ has a relaxed length, $\boldsymbol{L_0}$. A mass, $\boldsymbol{M}$ is attached to the end of the spring and comes to equilibrium. With the mass and spring at rest, you very slowly pull down on the mass so that the spring stretches an *additional* length, $\boldsymbol{s_i}$. At that point, you give the mass an upward initial speed, $\boldsymbol{v_i}$.

Which of the following equations will you need to solve to determine the maximum compression, $\boldsymbol{s_{max}}$ of the spring relative to the equilibrium position? Consider the spring, mass and Earth as the system.



A) $\left(0-\frac{1}{2}mv_i^2\right)+\left(\frac{1}{2}k_s s_{max}^2-\frac{1}{2}k_s s_i^2\right)+\left(mgs_{max}-mg(-s_i)\right)=0$

B) $\left(0-\frac{1}{2}mv_i^2\right)+\left(\frac{1}{2}k_s s_{max}^2-\frac{1}{2}k_s s_i^2\right)=0$

C) $\left(0-\frac{1}{2}mv_i^2\right)+\left(\frac{1}{2}k_s s_{max}^2-\frac{1}{2}k_s s_i^2\right)=\left(mgs_{max}-mg(-s_i)\right)$

D) $\left(0-\frac{1}{2}mv_i^2\right)=\left(\frac{1}{2}k_s s_{max}^2-\frac{1}{2}k_s s_i^2\right)$

E) None of the above

Problem 12: [8 points]

Starting from rest, a woman lifts a barbell of mass $\boldsymbol{m}$ with a constant force of $\boldsymbol{F}$ Newtons through a distance of $\boldsymbol{h}$ meters, at which point she is still lifting, and the barbell has acquired a speed of $\boldsymbol{v}$ m/s.

Let E_{woman} stand for the internal energy of the woman.

For the **system** consisting of the **woman + barbell + Earth**, which equation below is the correct application of the energy principle from the initial state with the barbell at rest to the final state with the barbell having moved upward a distance $\boldsymbol{h}$ and has a speed $\boldsymbol{v}$?

A) $\Delta E_{woman} + \left(\frac{1}{2}mv^2 - 0\right) + (mgh - 0) = Fh$

B) $\Delta E_{woman} + \left(\frac{1}{2}mv^2 - 0\right) + (mgh - 0) = 0$

C) $\Delta E_{woman} + \left(0 - \frac{1}{2}mv^2\right) + (0 - mgh) = 0$

D) $\Delta E_{woman} + \left(0 - \frac{1}{2}mv^2\right) + (0 - mgh) = Fh$

E) None of the above

Problem 13: [8 points]

A block of mass $\boldsymbol{M_A}$ and specific heat $\boldsymbol{C_A}$ has an initial temperature of $\boldsymbol{T_A}$. It is brought into thermal contact with a second block of mass $\boldsymbol{M_B}$ and specific heat $\boldsymbol{C_B}$ at temperature $\boldsymbol{T_B}$.

Which equation should you solve to find the final equilibrium temperature $\boldsymbol{T}$?

A) $M_A C_A (T - T_A) + M_B C_B (T - T_B) = 0$

B) $M_A C_A (T - T_A) + M_B C_B (T_B - T) = 0$

C) $M_A C_A (T - T_B) + M_B C_B (T_A - T) = 0$

D) $M_A C_A (T - T_B) + M_B C_B (T - T_A) = 0$

E) None of the above

Problem 14: [8 points]

In a rough attempt to repeat Joule's famous experiment you begin with **1 kg** of water at room temperature in a not very well insulated container. You stir the water until a thermometer shows that its temperature increased by **1K**. In the process you did **5000 J** of work on the water by stirring it.

What is the magnitude of the energy transfer, $|\boldsymbol{Q}|$**,** from the water to its surroundings due to a temperature difference that occurred while you stirred? Note: the specific heat capacity of water is 4200 J/kg/K.

A) 0 J

B) 800 J

C) 4200 J

D) 5000 J

E) None of the above

Problem 15: [8 points]

A perfectly insulated house has a volume of 500 m^3 and air temperature 0°C. You bring in a closed bucket of 10 kg water at almost 100°C.

What will the approximate temperature be in the house after equilibration?

Use specific heat of water = 4200 J/K/kg, specific heat of air = 1000 J/K/kg, and density of air = 1.2 kg/m^3.

A) 1°C
B) 2°C
C) 5°C
D) 10°C
E) None of the above

Problem 16: [8 points]

A single falling coffee filter quickly reaches a constant terminal speed. At this speed, how does the magnitude of the force due to air resistance, $|\vec{F}_{air}|$ compare with the magnitude of the force due to gravity, $|\vec{F}_{grav}|$?

A) $|\vec{F}_{air}| > |\vec{F}_{grav}|$

B) $|\vec{F}_{air}| = |\vec{F}_{grav}|$

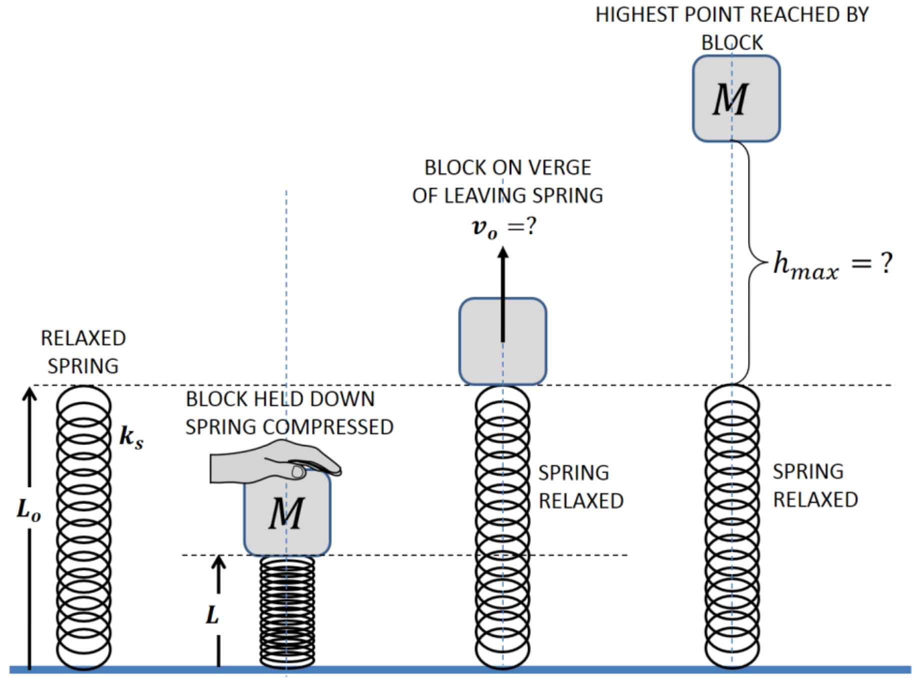
C) $|\vec{F}_{air}| < |\vec{F}_{grav}|$

D) The answer depends on other factors not provided

E) None of the above

Problems 17-19:

A spring of stiffness, $\boldsymbol{k_s}$ and un-stretched length, $\boldsymbol{L_0}$ is placed vertically on a horizontal surface. A block of mass $\boldsymbol{M}$ is initially held at rest pressing down on the top of the spring, such that the compressed length of the spring is $\boldsymbol{L}$. The block is in contact with, but not attached to the spring, so when you release the block, the spring pushes it up all the way to the top of the top of the un-stretched length of the spring, at which point it is launched into the air.



Problem 17: [<u>6 points</u>]

Three students present statements about how to find the speed $\boldsymbol{v_o}$ at which the block is launched into the air at the top of the spring. Which is correct?

<u>Amy</u>: You choose the block as the system and Earth and spring as the surroundings and your equation is: $\left(\frac{1}{2}Mv_0^2 - 0\right) = -Mg(L_0 - L) + \frac{1}{2}k_s(L_0 - L)^2$

<u>Beth</u>: You choose the block and spring as the system and Earth as the surroundings and your equation is : $\left(\frac{1}{2}Mv_0^2 - 0\right) + \left(0 - \frac{1}{2}k_s(L_0 - L)^2\right) = -Mg(L_0 - L)$

<u>Cathy</u>: You choose the block, spring, and Earth in the system, and nothing in the surroundings, then your equation is: $\left(\frac{1}{2}Mv_0^2 - 0\right) + Mg(L_0 - L) = \frac{1}{2}k_s(L_0 - L)^2$

A) Amy is correct, but Beth and Cathy are wrong.

B) Beth is correct, but Amy and Cathy are wrong.

C) Cathy is correct, but Amy and Beth are wrong.

D) Both Amy and Beth are correct, Cathy is wrong.

E) None of them are correct.

Problem 18: [5 points]

What is the maximum height, h_{max} (relative to the top of the uncompressed spring) achieved by the block before it starts to come down again?

A) $h_{max} = \frac{v_0^2}{2g}$

B) $h_{max} = \frac{v_0^2}{g}$

C) $h_{max} = \frac{2v_0^2}{g}$

D) $h_{max} = \frac{3v_0^2}{g}$

E) None of the above

Problem 19: [5 points]

What is the time t_{max} after it is launched, for the block to reach the ***highest point*** on its flight?

A) $t_{max} = \frac{v_0}{g}$

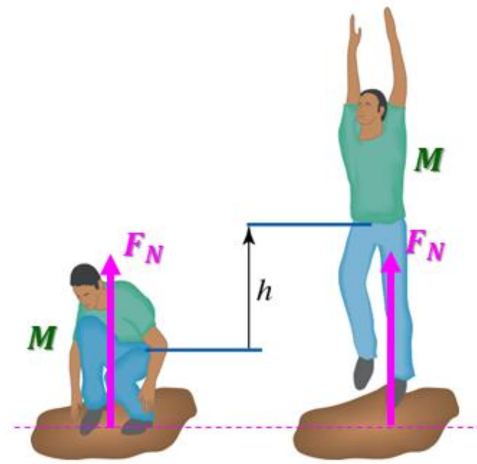
B) $t_{max} = \frac{2v_0}{g}$

C) $t_{max} = \frac{v_0}{2g}$

D) $t_{max} = \frac{v_0}{4g}$

E) None of the above

Problem 20-21:



Your friend, mass $\boldsymbol{M}$ jumps up from a crouched position to a vertical standing position, such that their center of mass moves vertically upward through height $\boldsymbol{h}$. During this process, the point of contact between your friend's feet and the ground is stationary. Your friend experiences a normal force $\boldsymbol{F_N}$ acting upward at the point of contact between the feet and the ground. Your friend's change in internal energy in the process is $\Delta\boldsymbol{E_{int}}$ and their change in kinetic energy due to their torso moving relative to the center of mass is $\Delta\boldsymbol{K_{rel}}$

Problem 20: [4 points]

Which of the following equations represents the energy principle of the ***point particle system*** as applied to your friend from the initial to the final positions shown above?

A) $\Delta K_{trans} = F_N h$

B) $\Delta K_{trans} + \Delta E_{int} + \Delta K_{rel} = -Mgh$

C) $\Delta K_{trans} = (F_N - Mg)h$

D) $\Delta K_{trans} + \Delta E_{int} + \Delta K_{rel} = (F_N - Mg)h$

E) None of the above

Problem 21: [4 points]

Which of the following equations represents the energy principle of the ***extended system*** as applied to your friend from the initial to the final positions shown above?

A) $\Delta K_{trans} = F_N h$

B) $\Delta K_{trans} + \Delta E_{int} + \Delta K_{rel} = -Mgh$

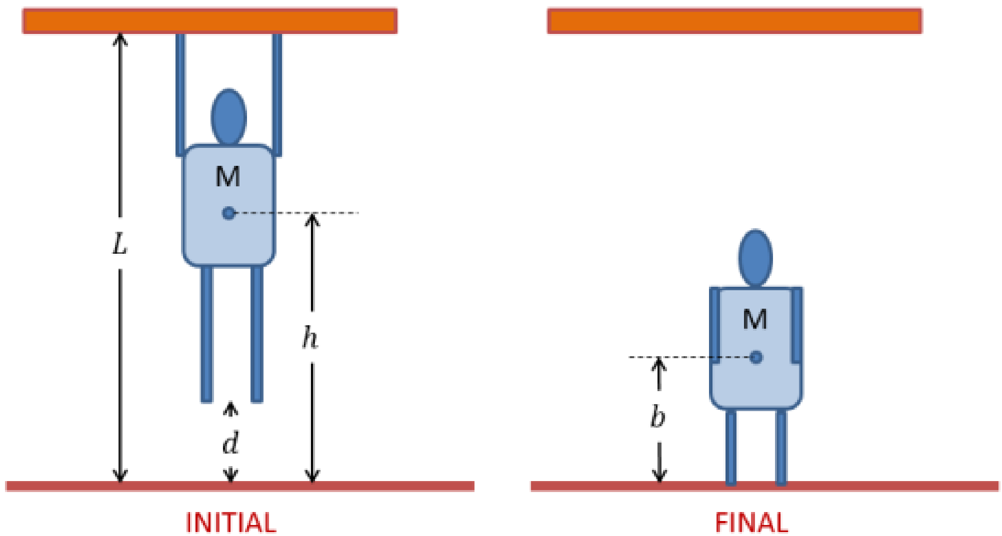
C) $\Delta K_{trans} = (F_N - Mg)h$

D) $\Delta K_{trans} + \Delta E_{int} + \Delta K_{rel} = (F_N - Mg)h$

E) None of the above

Problem 22-23:

You, mass $\boldsymbol{M}$ hang by your hands from a tree limb that is a height $\boldsymbol{L}$ above the ground, with your center of mass a height $\boldsymbol{h}$ above the ground, and your feet a height $\boldsymbol{d}$ above the ground. You then let yourself fall. You absorb the shock by bending your knees, ending up momentarily at rest in a crouched position with your center of mass a height $\boldsymbol{b}$ above the ground.



Problem 22: [4 points]

What is your ***kinetic energy*** at the instant your feet first touch the ground?

A) Mgh
B) $Mg(h-d)$
C) Mgd
D) $Mg(h-d-b)$
E) $Mg(h-b)$

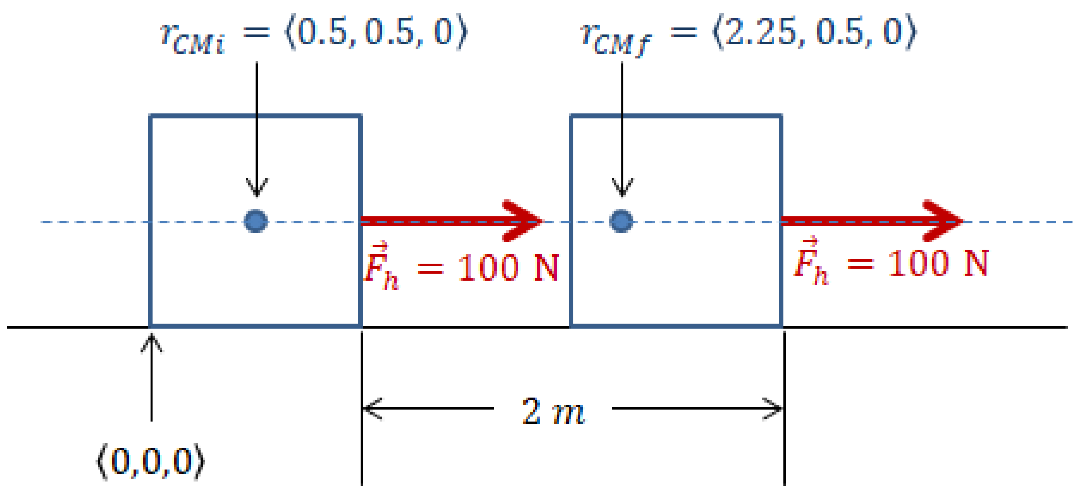
Problem 23: [4 points]

What is the ***change in internal energy*** in your body from the initial to final position?

A) $Mg(h-b)$
B) $-Mg(h-b)$
C) $-Mg(h-d-b)$
D) $Mg(h-d-b)$
E) $Mg(h-d)$

Problem 24: [8 points]

Using a string, you pull a 2.0-kg box along a nearly frictionless table with a constant force of 100 N, starting from rest. The box is full of liquid and is a cube of dimensions 1m x 1m x 1m. The center of mass of the system is initially located at $r_{CMi} = \langle 0.5, 0.5, 0\rangle\ m$ relative to the left, lower corner of the box. At some time later, your hand has pulled through a distance of 2 m, and the center of mass has shifted to $r_{CMf} = \langle 2.25, 0.5, 0\rangle$. The fluid and box is defined as "the system." There is no energy transferred thermally between the system and its surroundings.



What is the ***change in internal energy*** of the system? [Hint: You will first need to find the change in translational kinetic energy of the system.]

A) 50 J

B) 25 J

C) 175 J

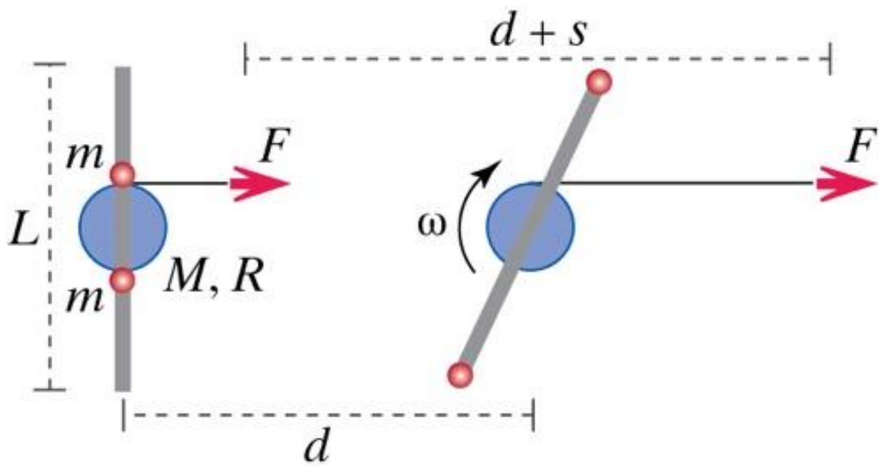
D) 75 J

E) 200 J

Problem 25: [8 points]

A rod of length $\boldsymbol{L}$ and negligible mass is attached to a uniform disk of mass $\boldsymbol{M}$ and radius $\boldsymbol{R}$. A string is wrapped around the disk, and you pull on the string with a constant magnitude force $\boldsymbol{F}$.

Two small balls each of mass m slide along the rod with negligible friction. The apparatus starts from rest, and when the center of the disk has moved a distance $\boldsymbol{d}$, a length of string $\boldsymbol{s}$ has come off the disk, and the balls have collided with the ends of the rod and stuck there. The apparatus slides on a nearly frictionless table.



What is the ***angular speed***, $\boldsymbol{\omega}$ of the disk at this instant?

Note: The moment of inertia of a disk is $I = \frac{1}{2}MR^2$.

A) $\omega = \sqrt{\frac{2Fs}{2mL^2+MR^2}}$

B) $\omega = \sqrt{\frac{2Fs}{mL^2+MR^2}}$

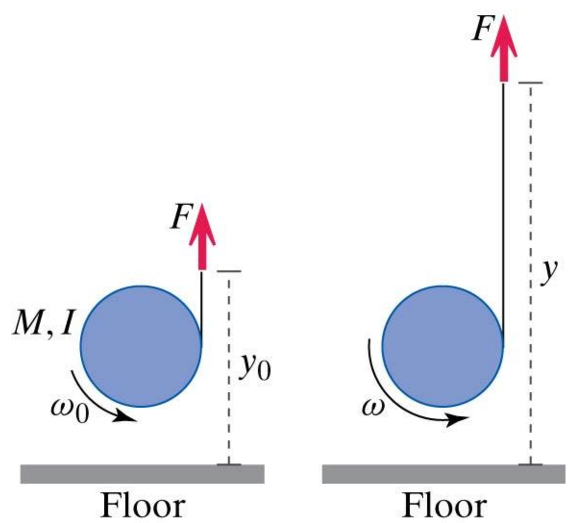
C) $\omega = \sqrt{\frac{Fs}{mL^2+MR^2}}$

D) $\omega = \sqrt{\frac{2Fs}{4mL^2+MR^2}}$

E) $\omega = \sqrt{\frac{4Fs}{mL^2+MR^2}}$

Problem 26: [8 points]

String is wrapped around an object of mass $\boldsymbol{M}$ and moment of inertia $\boldsymbol{I}$. With your hand you pull the string straight up with some constant force $\boldsymbol{F}$ such that the center of the object does not move up or down, but the object spins faster and faster. When your hand is a height $\boldsymbol{y_0}$ above the floor, the object has an angular speed of $\boldsymbol{\omega_0}$.



What is the ***angular speed, $\boldsymbol{\omega}$*** of the object, when your hand has risen to a height $y = y_0 + \Delta y$ above the floor?

A) $\omega = \sqrt{\frac{2Mg\Delta y}{I} + \omega_0^2}$

B) $\omega = \sqrt{\frac{2Mg\Delta y}{I} - \omega_0^2}$

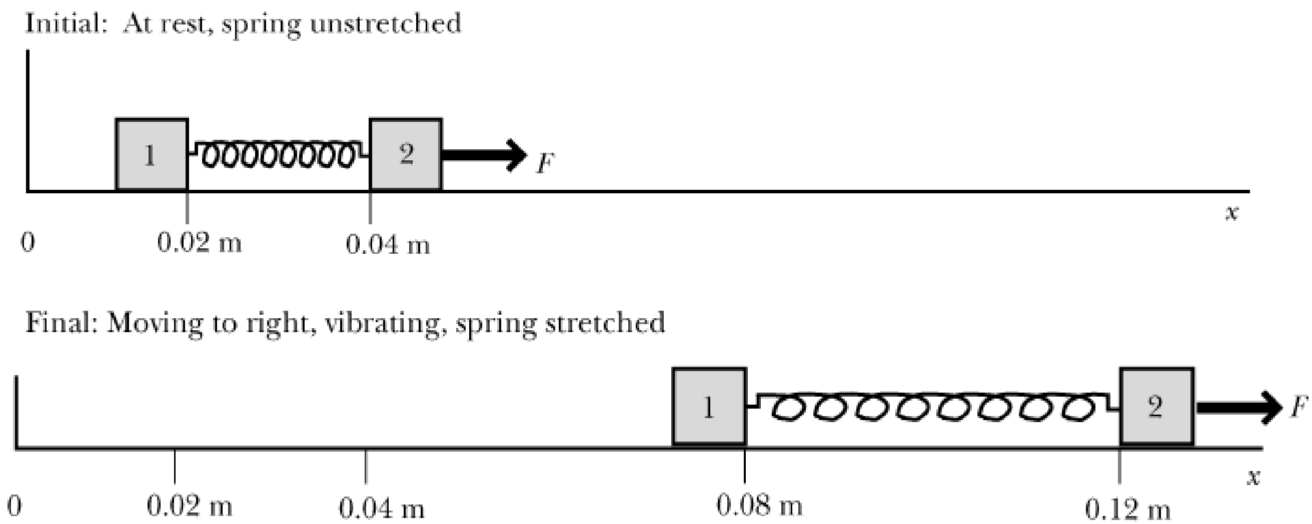
C) $\omega = \sqrt{\frac{2Mg}{I} + \omega_0^2}$

D) $\omega = \sqrt{\frac{2Mg\Delta y}{I}}$

E) $\omega = \sqrt{\frac{2Mgy}{I} - \omega_0^2}$

Problem 27-28

Two identical masses on a frictionless surface are connected to each other with a spring. The initial and final configurations of the masses are shown in the figure. Initially, the spring is at its equilibrium length. The rightmost mass is pulled with a force $\boldsymbol{F} = 100\ N$ to the right.



Problem 27: [4 points]

What is the ***change in translational kinetic energy*** of the system from the initial to the final position?

A) 15.0 J
B) 8.0 J
C) 7.0 J
D) 1.0 J
E) None of the above

Problem 28: [4 points]

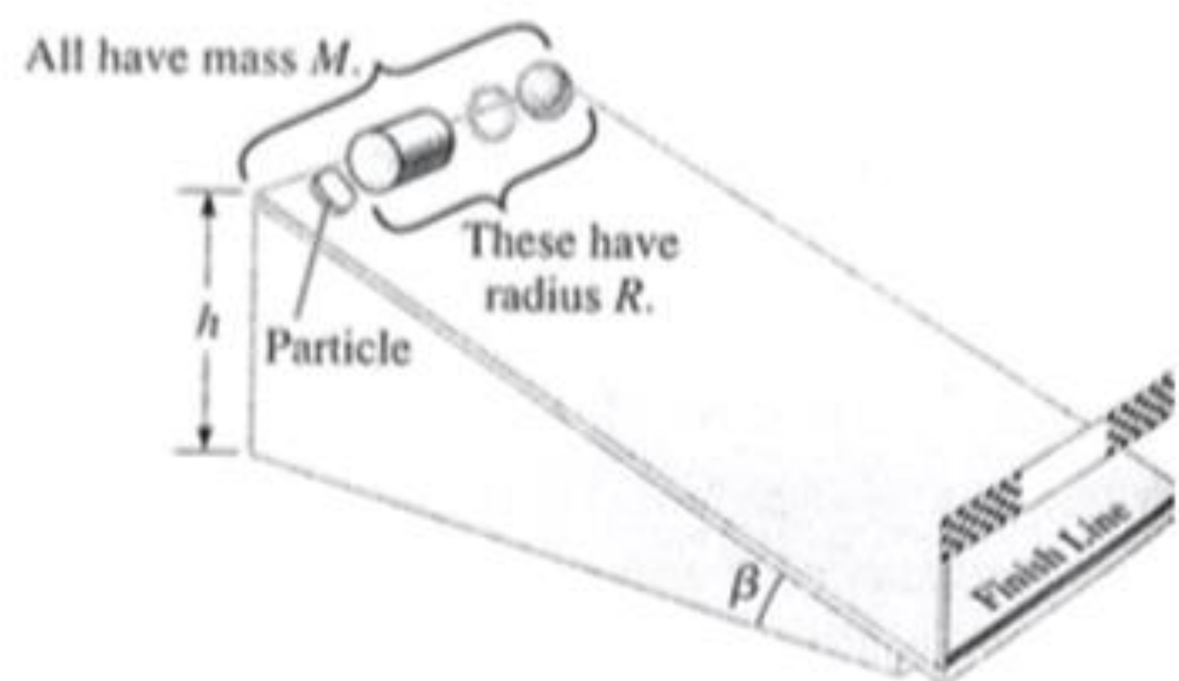
What is the ***change in internal energy*** of the system from the initial to the final position?

A) 15.0 J
B) 8.0 J
C) 7.0 J
D) 1.0 J
E) None of the above

Problem 29: [8 points]

Four objects of the same mass, $\boldsymbol{M}$ are initially at rest and positioned as shown on an inclined plane of height $\boldsymbol{h}$. The "particle" is a flat, slippery object that can slide down the plane without friction. The other objects, all having the same radius, $\boldsymbol{R}$ are a solid cylinder, a hoop and a solid sphere that roll down the plane without slipping.

Note: $I_{hoop} = MR^2$ $\quad I_{cylinder} = \frac{1}{2}MR^2$ $\quad I_{sphere} = \frac{2}{5}MR^2$



If they are all released at the same time, in what order (first to last) will the objects reach the finish line?

A) particle, cylinder, hoop, sphere

B) particle, sphere, cylinder, hoop

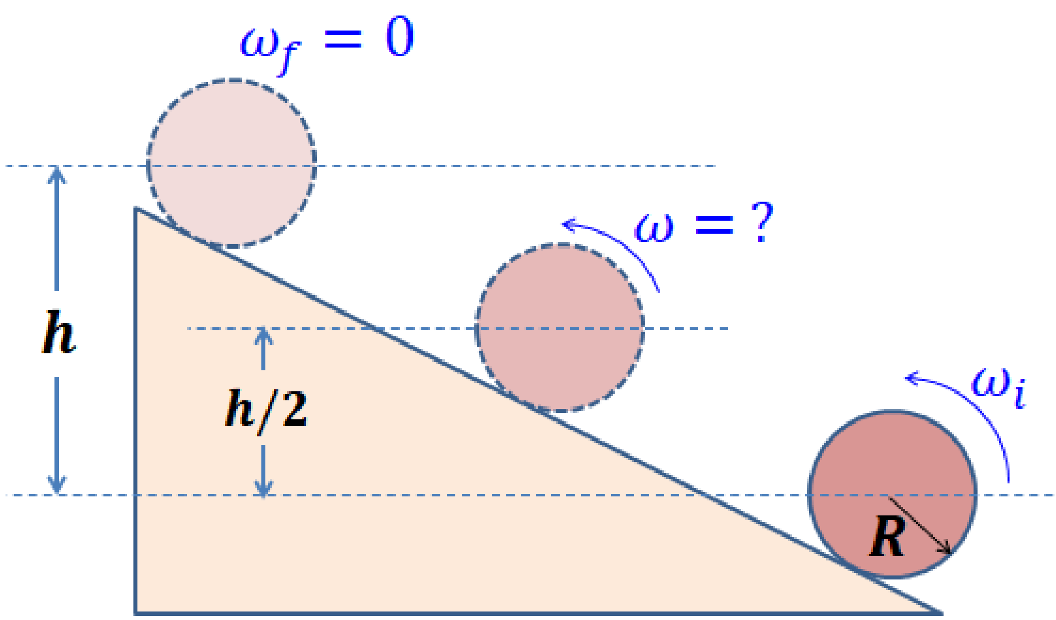
C) particle, hoop, sphere, cylinder

D) hoop, cylinder, sphere, particle

E) sphere, cylinder, hoop, particle

Problem 30: [8 points]

A cylinder of mass $\boldsymbol{M}$, radius $\boldsymbol{R}$, is given an initial angular speed, $\boldsymbol{\omega_i}$ up an inclined plane. The cylinder rolls without slipping and comes to rest at a height $\boldsymbol{h}$ above its initial position.



What is the cylinder's **angular speed,** $\boldsymbol{\omega}$ when it reaches a height of $\boldsymbol{h/2}$ above its initial position?

Note: Moment of inertia of the cylinder is $I = \frac{1}{2}MR^2$

A) $\omega = \frac{\omega_i}{4}$

B) $\omega = \frac{\omega_i}{2}$

C) $\omega = \frac{\omega_i}{\sqrt{2}}$

D) $\omega = \frac{\omega_i}{\sqrt{8}}$

E) $\omega = \frac{\omega_i}{8}$