Physics 110

Exam #1

April 24, 2026

Name___________________________________

Please read and follow these instructions carefully:

- Read all problems carefully before attempting to solve them.
- Your work must be legible, and the organization clear.
- You must show all work, including correct vector notation.
- You will not receive full credit for correct answers without adequate explanations.
- You will not receive full credit if incorrect work or explanations are mixed in with correct work. So, erase or cross out anything you don't want graded.
- Make explanations complete but brief. Do not write a lot of prose.
- Include diagrams.
- Show what goes into a calculation, not just the final number. For example, $|\vec{p}| \approx m|\vec{v}| = (5kg) \times (2\frac{m}{s}) = 10\frac{kg \cdot m}{s}$
- Give standard SI units with your results unless specifically asked for a certain unit.
- Unless specifically asked to derive a result, you may start with the formulas given on the formula sheet including equations corresponding to the fundamental concepts.
- Go for partial credit. If you cannot do some portion of a problem, invent a symbol and/or reasonable value for the quantity you cannot calculate (explain that you are doing this), and use it to do the rest of the problem.
- Each free-response part is worth 4 points

Problem #1	/24
Problem #2	/24
Problem #3	/24
Total	/72

I affirm that I have carried out my academic endeavors with full academic honesty.

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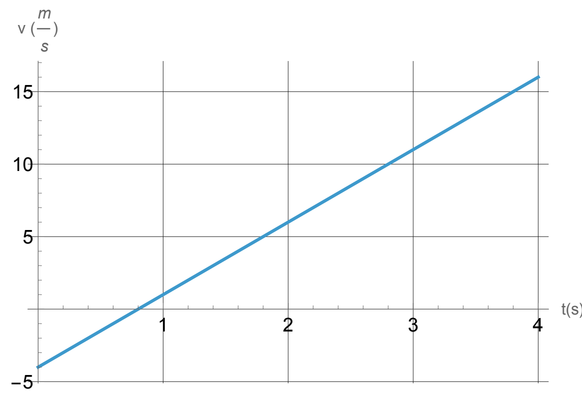
1. Consider the velocity versus time plot shown on the right. An object of mass m_1 moves in straight line motion along the x-axis with the motion starting at the origin.



   a. What is the acceleration of the object of mass m_1 and explain how you determined the value?

$$a = \frac{\Delta v}{\Delta t} = \frac{16\frac{m}{s} - \left(-4\frac{m}{s}\right)}{4s - 0s} = 5\frac{m}{s^2}$$

Since this is a velocity versus time plot, the acceleration is the slope if the line.

   b. What is the expression for the velocity and the trajectory of the object of mass m_1 as a function of time? Be sure to put in numbers with units?

$$v_{fx} = v_{ix} + a_x t = -4\frac{m}{s} + 5\frac{m}{s^2}t$$

$$x_f = x_i + v_{ix}t + \frac{1}{2}a_x t^2 = -4\frac{m}{s}t + \frac{1}{2}\left(5\frac{m}{s^2}\right)t^2$$

   c. What is the location and velocity of the object of mass m_1 after a time $t = 12s$?

$$v_{fx} = v_{ix} + a_x t = -4\frac{m}{s} + 5\frac{m}{s^2} \times 12s = 56\frac{m}{s}$$

$$x_f = x_i + v_{ix}t + \frac{1}{2}a_x t^2 = -4\frac{m}{s} \times 12s + \frac{1}{2}\left(5\frac{m}{s^2}\right)(12s)^2 = 312m$$

d. Suppose a second object of mass m_2 starts from rest at the origin at the same time as the object of mass m_1 starts moving. That is, the block of mass m_1 passes the block of mass m_2 at time $t = 0$. At what time (or times) will the two objects be at the same location if the object of mass m_2 accelerates at a rate $a_2 = 2\frac{m}{s^2}$?

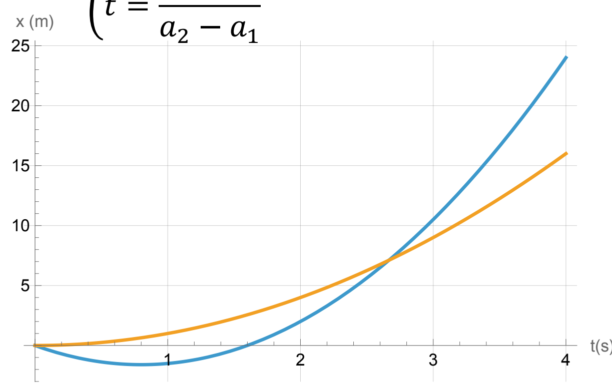
$$x_{f1} = x_{i1} + v_{ix1}t + \frac{1}{2}a_{x1}t^2 = v_{ix1}t + \frac{1}{2}a_{x1}t^2$$

$$x_{f2} = x_{i2} + v_{ix2}t + \frac{1}{2}a_{x2}t^2 = \frac{1}{2}a_{x2}t^2$$

$$x_{f1} = x_{f2} \rightarrow v_{ix1}t + \frac{1}{2}a_{x1}t^2 = \frac{1}{2}a_{x2}t^2 \rightarrow \begin{cases} t = 0 \\ t = \dfrac{2v_{ix1}}{a_2 - a_1} \end{cases}$$

$$t = \frac{2v_{ix1}}{a_2 - a_1} = \frac{2 \times \left(-4\frac{m}{s}\right)}{2\frac{m}{s^2} - 5\frac{m}{s^2}} = 2.7s$$

This can be seen too if we plot the trajectories of both objects.



e. Assuming there is a point in space that the object of mass m_2 is at the same location as the object of mass m_1, what will be the location of that point in space and what will be the speed of the object with mass m_2 at that point?

$$x_{f2} = \frac{1}{2}a_{x2}t^2 = \frac{1}{2}\left(2\frac{m}{s^2}\right)(2.7s)^2 = 7.3m$$

$$v_{fx2} = v_{ix2} + a_{2x}t = 2\frac{m}{s^2} \times 2.7s = 5.4\frac{m}{s}$$

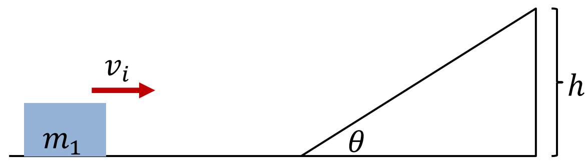
f. Fully describe the motion of the objects with masses m_1 and m_2. To earn full credit, be sure to use complete English sentences and physics terms.

Object 1: This object starts at the origin with an initial velocity that is negative. Its acceleration is positive, so it slows down to rest (as seen on the graph in part a) and the accelerates in the positive x-direction. This produces the positive sign for the velocity. The displacement of the object is initially in the negative x-direction and then after the object comes to rest, the object is displaced in the positive x-direction.

Object 2: This object starts from rest at the origin and accelerates in the positive x-direction. Its velocity increases linearly in time in the positive direction and its displacement is in the positive x-direction and increases as the square of time.

2. A block of mass $m_1 = 0.5kg$ is launched across a horizontal frictionless surface (the ground) as shown below, with an initial velocity $v_i = 4\frac{m}{s}$. The block then encounters a ramp inclined at an angle of $\theta = 50^0$ measured with respect to the horizontal surface. Friction exists only along the ramp's surface with coefficient of friction $\mu = 0.2$.

   a. From a carefully labeled free-body diagram when the block is on the ramp, what is the magnitude and direction of the acceleration of the block of mass m_1 on the ramp?



   Taking parallel to and up the ramp as the positive x-direction and perpendicular to and away from the ramp as the positive y-direction we have:

   In the y-direction:

   $$F_N - F_{Wy} = F_N - m_1 g\cos\theta = m_1 a_y = 0 \rightarrow F_N = m_1 g\cos\theta$$

   In the x-direction:

   $$-F_{Wx} - F_{fr} = F_{Wx} - \mu F_N = -m_1 g\sin\theta - \mu m_1 g\cos\theta = m_1 a_x$$

   $$a_x = -(\sin\theta + \mu\cos\theta)g = -(\sin 50 + 0.2\cos 50) \times 9.8\frac{m}{s^2} = -8.77\frac{m}{s^2}$$

   The acceleration is $8.77\frac{m}{s^2}$ directed down the ramp.

   b. From your carefully labeled free-body diagram in part a, what is the value of h when the block comes to rest on the ramp?

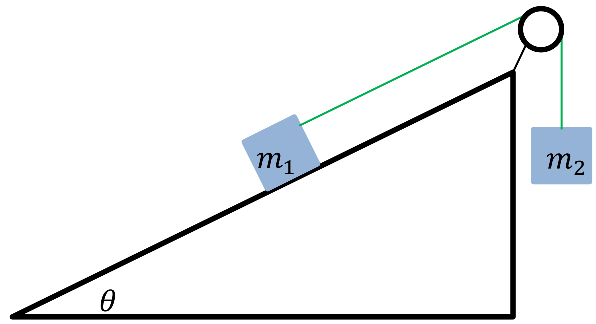
   The horizontal distance along the ramp:

   $$v_{fx}^2 = v_{ix}^2 + 2a_x\Delta x \rightarrow \Delta x = \frac{v_{fx}^2 - v_{ix}^2}{2a_x} = \frac{-\left(4\frac{m}{s}\right)^2}{-2 \times 8.77\frac{m}{s^2}} = x_f - x_i = x_f = 0.91m$$

   The vertical height:

   $$\sin\theta = \frac{h}{\Delta x} = \frac{h}{x_f} \rightarrow h = x_f\sin\theta = 0.91m\sin 50 = 0.7m$$

c. Suppose that the block of mass $m_1 = 0.5kg$ were instead connected to a block of mass $m_2 = 1kg$ by a light string that passes over a massless pulley as shown below. From a carefully labeled free-body diagram, if the block of mass were released from rest, what the magnitude of the acceleration of the system of masses? Assume friction still exists on the ramp with coefficient of friction $\mu = 0.2$ and that $\theta = 50^0$.



Taking parallel to and up the ramp as the positive x-direction and perpendicular to and away from the ramp as the positive y-direction we have:

In the y-direction for the block of mass m_1:

$$F_N - F_{W1y} = F_N - m_1 g \cos\theta = m_1 a_y = 0 \rightarrow F_N = m_1 g \cos\theta$$

In the x-direction for the block of mass m_1:

$$F_T - F_{Wx1} - F_{fr} = F_T - F_{Wx1} - \mu F_N = F_T - m_1 g \sin\theta - \mu m_1 g \cos\theta = m_1 a$$

Taking vertically up as the positive y-direction, we have for the block of mass m_2:

$$F_T - F_{W2} = -m_2 a \rightarrow F_T = m_2 g - m_2 a$$

$$\rightarrow m_2 g - m_2 a - m_1 g \sin\theta - \mu m_1 g \cos\theta = m_1 a$$

$$a = \left(\frac{m_2 - m_1 \sin\theta - \mu m_1 \cos\theta}{m_1 + m_2}\right) g$$

$$a = \left(\frac{1kg - 0.5kg(\sin 50 + 0.2\cos 50)}{0.5kg + 1kg}\right) \times 9.8\frac{m}{s^2} = 3.6\frac{m}{s^2}$$

d. Using your carefully labeled free-body diagram, what is the magnitude of the tension force in the rope connected to the block of mass m_2?

$$F_T = m_2 g - m_2 a = 1kg \times \left(9.8\tfrac{m}{s^2} - 3.6\tfrac{m}{s^2}\right) = 6.2N$$

or

$$F_T = m_1 g \sin\theta + \mu m_1 g \cos\theta + m_1 a$$

$$F_T = 0.5kg\left((\sin 50 + 0.2\cos 50) \times 9.8\frac{m}{s^2} + 3.6\frac{m}{s^2}\right) = 6.2N$$

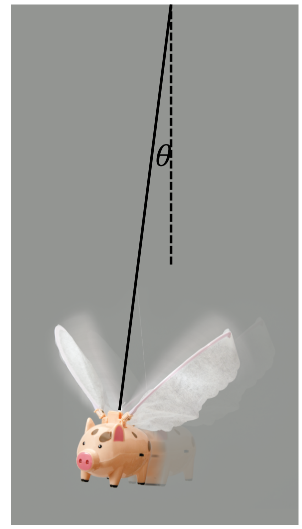
g. When released from rest, what will be the speed of the block of mass m_1 if m_1 slides a distance $d = 0.5m$ parallel to and up the ramp?

$$v_{fx}^2 = v_{ix}^2 + 2a_x\Delta x \rightarrow v_f = \sqrt{2a\Delta x} = \sqrt{2 \times 3.6\frac{m}{s^2} \times 0.5m} = 1.9\frac{m}{s}$$

h. When released from rest, how long will it take the block of mass m_1 to slide a distance $d = 0.5m$ parallel to and up the ramp?

$$x_f = x_i + v_{ix}t + \tfrac{1}{2}a_x t^2 = \tfrac{1}{2}at^2 \rightarrow t = \sqrt{\frac{2x_f}{a}} = \sqrt{\frac{2 \times 0.5m}{3.6\frac{m}{s^2}}} = 0.53s$$

3. A plastic pig of mass $m = 120g$ is tethered to a string of length $L = 2.5m$ and flies in a horizontal circle at a speed v. While flying the string makes an angle $\theta = 20^0$ measured with respect to the vertical as shown in the figure on the right.



a. Starting from a clearly labeled free-body diagram, what would be the magnitude of the tension force in the string?

Assuming a standard cartesian coordinate system with to the right the positive x-direction and up the positive y-direction we have:

In the x-direction:

$$F_T \sin\theta = m\frac{v^2}{R}$$

In the y-direction:

$$F_T \cos\theta = mg \rightarrow F_T = \frac{mg}{\cos\theta} = \frac{0.120kg \times 9.8\frac{m}{s^2}}{\cos 20} = 1.25N$$

b. Using the free-body diagram that you drew in part a, what is the assumed constant speed of the pig as it is in flight?

$$F_T \sin\theta = \left(\frac{mg}{\cos\theta}\right)\sin\theta = mg\tan\theta = m\frac{v^2}{R} \rightarrow v = \sqrt{Rg\tan\theta}$$

$$v = \sqrt{Lg\sin\theta\tan\theta} = \sqrt{2.5m \times 9.8\frac{m}{s^2}\sin 20\tan 20} = 1.75\frac{m}{s}$$

Where, $\sin\theta = \frac{R}{L} \rightarrow R = L\sin\theta$

c. Suppose at some instant that the string snaps and the pig is launched horizontally from a height $y = 1.5m$ above the floor. What is the time-of-flight of the pig to the floor?

Assuming the same coordinate system above, we have:

$$y_f = y_i + v_{iy}t + \frac{1}{2}a_y t^2 \rightarrow -y = -\frac{1}{2}gt^2 \rightarrow t = \sqrt{\frac{2y}{g}} = \sqrt{\frac{2 \times 1.5m}{9.8\frac{m}{s^2}}} = 0.55s$$

d. How far horizontally from where the pig was launched does it land on the floor?

$$x_f = x_i + v_{ix}t + \frac{1}{2}a_x t^2 \rightarrow x = v_{ix}t = 1.75\frac{m}{s} \times 0.55s = 0.96m$$

Or, $0.96m$ in any direction, determined by where the pig was launched from.

e. What is the impact velocity of the pig with the floor?

$$v_f = \sqrt{v_{fx}^2 + v_{fy}^2} = \sqrt{\left(1.75\frac{m}{s}\right)^2 + \left(-5.39\frac{m}{s}\right)^2} = 5.66\frac{m}{s}$$

Where, $v_{fx} = v_{ix} + a_x t = v_{ix} = 1.75\frac{m}{s}$ and

$$v_{fy} = v_{iy} + a_y t = -gt = -9.8\frac{m}{s^2} \times 0.55s = -5.39\frac{m}{s}$$

$$\tan\phi = \frac{v_{fy}}{v_{fx}} \rightarrow \phi = \tan^{-1}\left(\frac{v_{fy}}{v_{fx}}\right) = \tan^{-1}\left(\frac{-5.39\frac{m}{s}}{1.75\frac{m}{s}}\right) = -72^0$$

Or 72^0 below the negative x-axis (or with respect to the positive x-axis, this is $360^0 - 72^0 = 288^0$).

f. What is the impact force that the pig hits the floor with if it takes $t = 50ms$ to bring the pig to rest?

$$F = ma = m\frac{\Delta v}{\Delta t} = \left|0.12kg \times \left(\frac{0\frac{m}{s} - 5.66\frac{m}{s}}{50 \times 10^{-3}s}\right)\right| = 13.2N \text{ in magnitude}$$

The direction is 180^0 from the direction of the impact velocity. With respect to the impact angle, (-72^0) then the angle is $= 180^0 - 72^0 = 108^0$ (or with respect to the positive x-axis) $288^0 - 180^0 = 108^0$) measured from the positive x-axis.