Physics 110

Exam #1

April 18, 2025

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, $\left|\vec{p}\right| \approx m\left|\vec{v}\right| = (5kg)\times\left(2\,\frac{m}{s}\right) = 10\,\frac{kg\cdot m}{s}$
- 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 6 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. A person on the ground throws a ball upwards from the street next to a tall building. The ball is seen to pass by a widow ($29m$ above the street) with a vertical speed of $18.2\frac{m}{s}$.

   a. What was the initial speed of the ball that was thrown by the person on the street? Assume that the ball is thrown directly from the ground.

   Taking the origin to be at the ground where the ball was launched from and up from the ground to be the positive y-direction we have:

   $$v_{fy}^2 = v_{iy}^2 + 2a_y\Delta y \rightarrow v_{fy}^2 = v_{iy}^2 - 2g\Delta y \rightarrow v_{iy}^2 = v_{fy}^2 + 2g\Delta y$$

   $$v_{iy} = \sqrt{v_{fy}^2 + 2g\Delta y} = \sqrt{\left(18.2\frac{m}{s}\right)^2 + 2 \times 9.8\frac{m}{s^2} \times 29m} = 30\frac{m}{s}$$

   b. What is the maximum height reached by the ball and how long does it take the ball to reach maximum height? Measure this time from it was initially thrown from the ground.

   Maximum height is when the ball stops rising, so $v_{fy} = 0$.

   $$v_{fy}^2 = v_{iy}^2 + 2a_y\Delta y \rightarrow 0 = v_{iy}^2 - 2g\Delta y \rightarrow \Delta y = \frac{v_{iy}^2}{2g} = \frac{\left(30\frac{m}{s}\right)^2}{2 \times 9.8\frac{m}{s^2}} = 45.9m$$

   The time to maximum height is given by:
   $v_{fy} = 0 = v_{iy} + a_y t = v_{iy} - gt_{rise}$

   $$t_{rise} = \frac{v_{iy}}{g} = \frac{30\frac{m}{s}}{9.8\frac{m}{s^2}} = 3.1s$$

c. Suppose that someone looking out of the window sees the ball as it passes the window on its way up. How long will it take for the person looking out the window to see the ball again on its way down? Assume the person sees the ball at the same point on the way up as on the way down.

Taking the initial position of the ball, when the ball passes the person in the window on the way up y_i, and the position of the ball when it passes the person in the window on the way down y_f, we have $y_f = y_i$.

$$y_f = y_i + v_{iy}t + \frac{1}{2}a_y t^2 \rightarrow 0 = \left(v_{iy} - gt\right)t$$

$t = 0$ when the ball first passes the window on the way up.

$t = \frac{v_{iy}}{2g} = \frac{18.2\frac{m}{s}}{2\times 9.8\frac{m}{s^2}} = 3.7s$ for the time on the way back down. So it takes the person in the window $3.7s$ to see the ball return.

d. At the exact moment the person on the ground launched their ball upwards, another person (located at y_{max}) throws a ball downward with an initial velocity of $v_{iy2} = -5\frac{m}{s}$. Calling ball #1 the ball launched from the ground and ball #2 the ball thrown downward from y_{max}, at what time do the balls pass each other and how far above the ground are they when they pass each other?

Taking the ground to be the origin of my coordinate system we can write the trajectories of both balls.

Ball #1

$$y_{f1} = y_{i1} + v_{iy1}t + \frac{1}{2}a_{y1}t^2 \rightarrow y_{f1} = v_{iy1}t - \frac{1}{2}gt^2$$

Ball #2

$$y_{f2} = y_{i2} + v_{iy2}t + \frac{1}{2}a_{y2}t^2 \rightarrow y_{f2} = y_{max} - v_{iy2}t - \frac{1}{2}gt^2$$

To pass each other $y_{f1} = y_{f2}$.

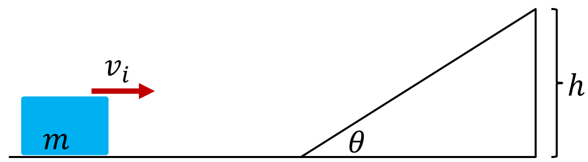
$$y_{f1} = y_{f2} \rightarrow v_{iy1}t - \frac{1}{2}gt^2 = y_{max} - v_{iy2}t - \frac{1}{2}gt^2$$

$$t = \frac{y_{max}}{v_{iy1} + v_{iy2}} = \frac{45.9m}{30\frac{m}{s} + 5\frac{m}{s}} = 1.31s$$

$$y_{f1} = v_{iy1}t - \frac{1}{2}gt^2 = \left(30\frac{m}{s} \times 1.31s\right) - \frac{1}{2} \times 9.8\frac{m}{s^2} \times (1.31s)^2 = 30.9m$$

2. A block of mass $m = 0.5kg$ is launched from rest across a frictionless horizontal surface as shown below, with an initial velocity $v_i = 12\frac{m}{s}$. The block then encounters a ramp inclined at an angle of $\theta = 40^0$measured with respect to the horizontal. Friction exists only along the ramps surface with coefficient of friction $\mu = 0.4$.

   a. What is the acceleration of the block when the block is sliding up the ramp? Take up the ramp as the positive x-direction.



In the x-direction:

$$F_{net,x} = -F_W \sin\theta - \mu F_N = -mg\sin\theta - \mu mg\cos\theta = ma_x$$

$$a_x = -g\sin\theta - \mu g\cos\theta = -(\sin 40 + 0.4\cos 40) \times 9.8\frac{m}{s^2}$$

$$a_x = -9.3\frac{m}{s^2}$$

In the y-direction:

$$F_{net,y} = F_N - F_W\cos\theta = F_N - mg\cos\theta = ma_y = 0 \rightarrow F_N = mg\cos\theta$$

   b. What is the speed of the block at the top of the ramp if the right end of the ramp is $h = 2.5m$ above the ground?

$$v_{fx}^2 = v_{ix}^2 + 2a_x\Delta x = \left(12\frac{m}{s}\right)^2 - 2 \times 9.3\frac{m}{s^2} \times \left(\frac{2.5m}{\sin 40}\right) = 8.47\frac{m}{s}$$

c. How far horizontally does the block travel from where it leaves the ramp and how long does it take the block to come back to the ground from the time it leaves the top of the ramp?

Taking to the right and up from the ground as the positive x- and y-directions respectively we have:

$$y_f = y_i + v_{iy}t + \frac{1}{2}a_y t^2$$

$$-h = (v_i \sin\theta)t - \frac{1}{2}gt^2$$

$$4.9t^2 - (8.47\sin 40)t - 2.5 = 0$$

$$t = \begin{cases} -0.35s \\ 1.46s \end{cases}$$

The time of flight of the box is $t = 1.7s$.

The horizontal distance covered by the box is:

$$x_f = x_i + v_{ix}t + \frac{1}{2}a_x t^2 = v_{ix}t = \left(8.47\frac{m}{s}\cos 40\right) \times 1.46s = 9.47m$$

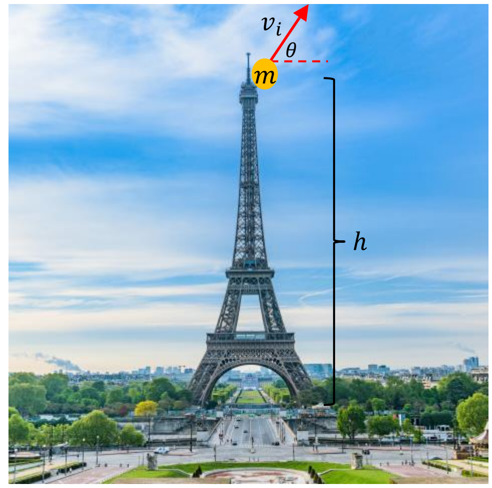
d. Suppose that when the block leaves the ramp, it were subject to air resistance which produces a constant force F_{air} on the block everywhere in the direction opposite to the velocity of the block. If we were to take air resistance into account, what affect would it have on the motion of the block through the air? There are no calculations involved in this question. To earn full credit, you must answer the following questions fully. What happens to the flight time of the block when it leaves the ramp in the presence of air and will the horizontal distance traveled by the block increase, decrease, or remain the same? Will the impact speed of the block with the ground increase, decrease, or remain the same?

The time of flight is governed by the vertical fall. So, nothing happens to the time of flight if air resistance is included.

Since air resistance opposes the velocity, we introduce a horizontal acceleration and a second vertical acceleration (in addition to that due to gravity). Thus, the horizontal distance traveled will be reduced and the block will not go as far.

Since there are additional accelerations in the x- and y-directions that oppose the velocity, the impact speeds in each direction will be reduced and the total impact speed will be reduced.

3. A ball of mass $m = 250g$ is launched from the top of the Eiffel Tower in Paris, France. The ball is launched at an angle of 40^0 measured with respect to the horizontal at a speed of $v_i = 25\frac{m}{s}$. The ball strikes the ground $t = 10s$ after it was launched.



https://www.architecturaldigest.com/story/eiffel-tower-everything-you-need-to-know

a. What is the height h of the Eiffel Tower and what is the maximum height the ball reaches above the ground?

Taking the base of the building as the origin with to the right and up the positive x- and y-directions respectively, we have:

$$y_f = y_i + v_{iy}t + \frac{1}{2}a_y t^2$$
$$0 = h + v_{iy}t - \frac{1}{2}gt^2 \rightarrow h = \frac{1}{2}gt^2 - (v_i \sin\theta)t$$
$$h = \frac{1}{2} \times 9.8\frac{m}{s^2} \times (10s)^2 - \left(25\frac{m}{s}\sin 40\right) \times 10s = 329.3m$$

The time to rise to maximum height:

$$v_{fy} = v_{iy} + a_y t_{rise} \rightarrow 0 = v_i \sin\theta - gt_{rise} \rightarrow t_{rise} = \frac{v_i \sin\theta}{g} = \frac{25\frac{m}{s}\sin 40}{9.8\frac{m}{s^2}}$$
$$t_{rise} = 1.6s$$

The maximum height above the ground:
$$y_f = y_i + v_{iy}t + \frac{1}{2}a_y t^2$$
$$y_f = 329.3m + \left(25\frac{m}{s} \times 1.6s \times \sin 40\right) - \frac{1}{2} \times 9.8\frac{m}{s^2} \times (1.6s)^2$$
$$y_f = 342.5m$$

b. What is the impact velocity of the ball with respect to the ground?

$$v_{fx} = v_{ix} + a_x t_{tof} = v_{ix} = v_i \cos\theta = 25\frac{m}{s}\cos 40 = 19.2\frac{m}{s}$$

$$v_{fy} = v_{iy} + a_y t_{tof} = 25\frac{m}{s}\sin 40 - 9.8\frac{m}{s^2} \times 10s = -81.9\frac{m}{s}$$

$$v_f = \sqrt{v_{fx}^2 + v_{fy}^2} = \sqrt{\left(19.2\frac{m}{s}\right)^2 + \left(-81.9\frac{m}{s}\right)^2} = 84.2\frac{m}{s}$$

$$\tan\phi = \frac{v_{fy}}{v_{fx}} \rightarrow \phi = \tan^{-1}\left(\frac{-81.9\frac{m}{s}}{19.2\frac{m}{s}}\right) = -76.8^0$$

c. When the ball strikes the ground, the ground exerts a force on the ball to bring it to rest from its impact speed. What are the horizontal ($F_{ball,ground,x}$) and vertical ($F_{ball,ground,y}$) components of the force that the ground exerts on the ball? Assume that the ball comes to rest in a time $t_g = 30ms$.

$$F_{ball,ground,x} = ma_x = m\left(\frac{v_{fx} - v_{ix}}{t}\right) = \frac{0.25kg \times \left(0\frac{m}{s} - 19.2\frac{m}{s}\right)}{30 \times 10^{-3}s} = -160N$$

$$F_{ball,ground,y} = ma_x = m\left(\frac{v_{fy} - v_{iy}}{t}\right) = \frac{0.25kg \times \left(0\frac{m}{s} - \left(-81.9\frac{m}{s}\right)\right)}{30 \times 10^{-3}s} = 682.5N$$

d. What force (magnitude and direction) did the ground exert on the ball in bringing the ball to rest? Is the direction reasonable? Explain.

$$F_{ground} = \sqrt{F^2_{ball,ground,x} + F^2_{ball,ground,y}}$$

$$F_{ground} = \sqrt{(-160N)^2 + (682.5N)^2} = 701N$$

This corresponds to a force of about $225lbs$. Imagine the force applied to you???

$$\tan\phi = \frac{v_{fy}}{v_{fx}} \rightarrow \phi = \tan^{-1}\left(\frac{682.5N}{-160N}\right) = 76.8^0$$

As I would expect. The force should be opposite the ball's velocity to slow the ball down.