Physics 120

Exam #1

January 23, 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 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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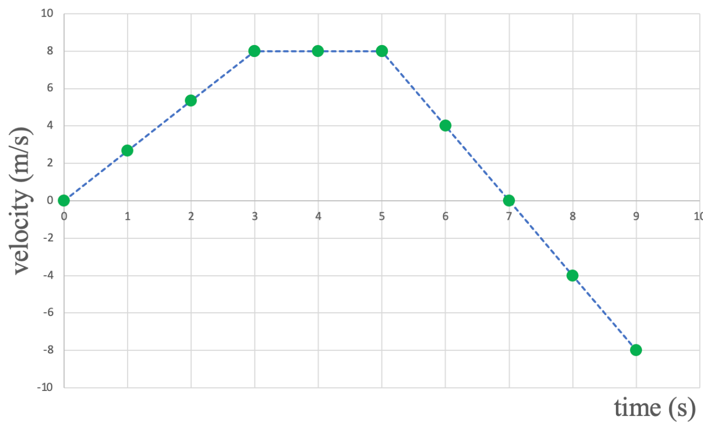
1. A car drives down the road and data are taken on the car's velocity as a function of time. The data are plotted on the velocity versus time graph shown below.



a. For the following time intervals ($0s < t < 3s$, $3s < t < 5s$, and $5s < t < 9s$), what are the average accelerations of the car?

For the time interval $0s$ to $3s$, the average acceleration is:

$$a_{avg} = \frac{\Delta v}{\Delta t} = \left(\frac{8\frac{m}{s} - 0\frac{m}{s}}{3s - 0s}\right) = 2.67\frac{m}{s^2}.$$

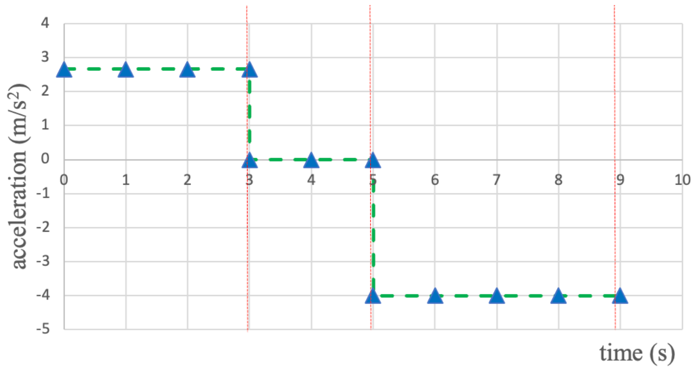
For the time interval $3s$ to $5s$, the average acceleration is:

$$a_{avg} = \frac{\Delta v}{\Delta t} = \left(\frac{8\frac{m}{s} - 8\frac{m}{s}}{5s - 3s}\right) = 0\frac{m}{s^2}.$$

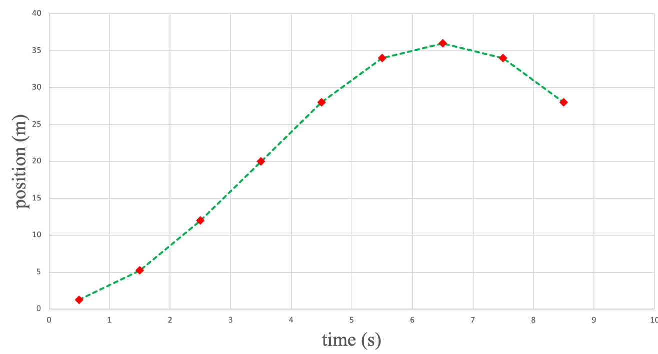
For the time interval $5s$ to $9s$, the average acceleration is:

$$a_{avg} = \frac{\Delta v}{\Delta t} = \left(\frac{-8\frac{m}{s} - (8\frac{m}{s})}{9s - 5s}\right) = -4\frac{m}{s^2}.$$

b. From the results of part a, construct the corresponding acceleration versus time graph on the axes below.



c. The position versus time graph corresponding to the motion of the car is shown below. Using the graph, fully explain position of the object as a function of time. To earn full credit, be sure to explain how this motion is obtained from the velocity versus time plot in part a and how the motion also supports your acceleration versus time plot in part b. You do not have to calculate any numbers for this part.



Over the interval $0s \leq t \leq 3s$, the car is accelerating and its position is increasing I n the positive x-direction at a quadratic rate as shown on the plot.

Over the interval $3s \leq t \leq 5s$, the acceleration of the car is zero and the velocity varies linearly in time and we see this as the position increasing at a linear rate still in the positive x-direction.

Over the interval $5s \leq t \leq 9s$, the car is accelerating opposite to its velocity. This causes the car to slow down and come to rest (somewhere between $6s$ and $7s$). This is the greatest point reached in the positive x-direction. The acceleration persists in the negative x-direction and the car accelerates in the negative x-direction. It's velocity increases in the negative x-direction and it moves towards the origin.

d. Using the position versus time graph in part c, what is the approximate total distance traveled by the car and the displacement of the car over the time interval $0s \leq t \leq 9s$.

The total distance traveled is approximately $36m$ over the time interval $0s \leq t \leq 6.5s$ and over the time interval $6.5s \leq t \leq 9s$ is $36m - 27m = 9m$. The sum of these two gives the total distance which is about $36m + 9m = 45m$.

Note this is not the displacement over the time interval $0s \leq t \leq 9s$. The displacement would have been approximately $\Delta x = 27m - 0m = 27m$ in the positive x-direction.

2. 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 when the ball 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 was looking out of the window as it passes the ball passes by 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 down as on the way up.

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 an identical ball downward with an initial velocity of $v_{iy2} = \langle 0, -5, 0\rangle\frac{m}{s}$. 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 $y_{f1} = y_{f2}$.

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

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

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

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 40^0measured 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:

$$\vec{r}_f = \vec{r}_i + \vec{v}_i t + \frac{1}{2}\vec{a}t^2$$
$$\langle x_f, y_f, z_f \rangle = \langle x_i + v_{ix}t + \frac{1}{2}a_x t^2, y_i + v_{iy}t + \frac{1}{2}a_y t^2, 0 \rangle$$

The vertical motion:

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

The time to rise to maximum height:

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

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 and how far horizontally from the launch point does the ball land on the ground?

$$\vec{v}_f = \vec{v}_i + \vec{a}t \rightarrow \langle v_{fx}, v_{fy}, v_{fz}\rangle = \langle v_{ix} + a_x t, v_{iy} + a_y t, 0\rangle$$

In the horizontal direction:

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

In the vertical direction:

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

As a vector:

$$\vec{v}_f = \langle v_{fx}, v_{fy}, v_{fz}\rangle = \langle 19.2, -81.9, 0\rangle\frac{m}{s}$$

As a magnitude and direction:

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

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

The horizontal displacement:

$$x_f = x_i + v_{ix}t + \frac{1}{2}a_x t^2 = v_{ix}t = 25\frac{m}{s} \cdot 10s \cdot \cos 40 = 191.5m$$

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.

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

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.