Physics – Lecture 2

Dundas Valley Highschool Co-Op

Physics

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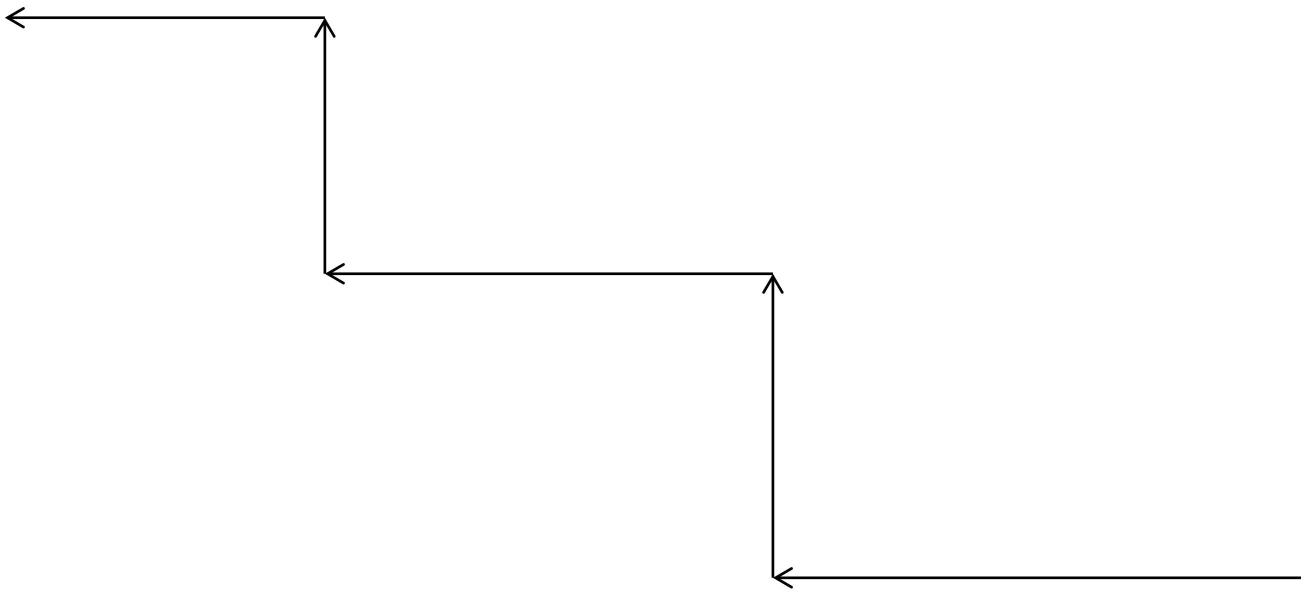
1. Displacement Review

- You (a physics student) are kidnapped by political-science majors (who are upset because you told them political science is not a real science). Although blindfolded, you can tell the speed of their car (by the whine of the engine), the time of travel (by mentally counting off the seconds), and the direction of travel (by turns along the rectangular street system). From these clues you know that you are taken along the following course:
  - 50 km/h for 2.0 min East turn 90 degrees to the right.
  - 20 km/h for 60.0s turn 90 degrees to the left.
  - 50 km/h for 60.0s turn 90 degrees to the right.
  - 20.0km/h for 2.0 min turn 90 degrees to the left.
  - 50 km/h for 30.0s.
- At that point, what is your displacement?

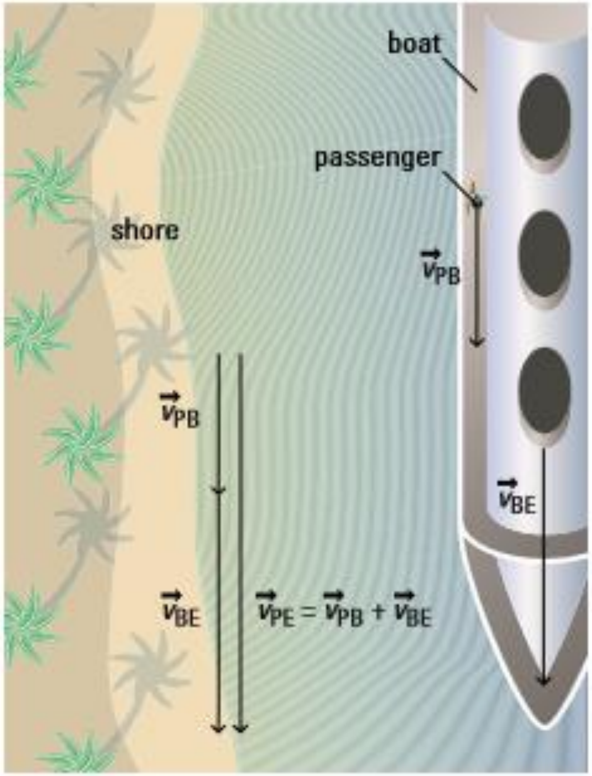
1. Displacement Review - Answer



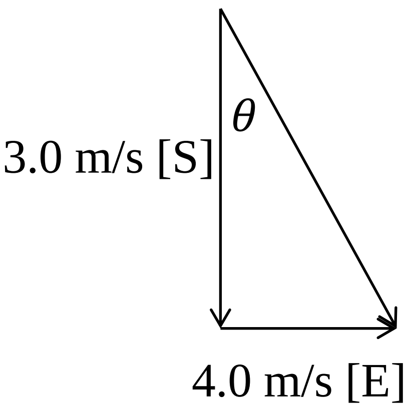
- 3.08 km East 18.9 degrees North

2. Relative Motion

- Suppose a large cruise boat is moving at a velocity of 9.0 m/s [S] relative to the shore and a passenger is jogging at a velocity of 4.0 m/s [S] relative to the boat. Relative to the shore, the passenger's velocity is the addition of the two velocities, 9.0 m/s [S] and 4.0 m/s [S], or 13.0 m/s [S]. The shore is one frame of reference, and the boat is another.



- Suppose while that cruise ship was moving 3.0 m/s [S] relative to the shore the jogger went 4.0 m/s [E] relative to the ship. What is the joggers velocity (relative to the shore)?



$$\vec{v}_{B,S} = 3.0\,\frac{\mathrm{m}}{\mathrm{s}}\,[\mathrm{S}]$$
$$\vec{v}_{J,B} = 4.0\,\frac{\mathrm{m}}{\mathrm{s}}\,[\mathrm{S}]$$
$$\vec{v}_{J,S} = ?\,\frac{\mathrm{m}}{\mathrm{s}}$$

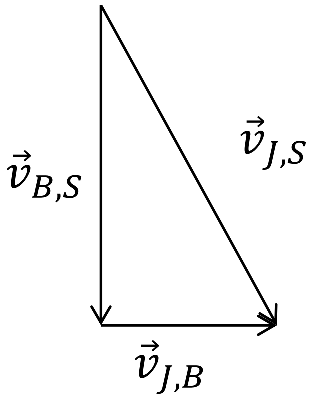
$$v_{J,S}^2 = v_{B,S}^2 + v_{J,B}^2$$
$$v_{J,S} = \sqrt{v_{B,S}^2 + v_{J,B}^2}$$

$$v_{J,S} = \sqrt{\left(3.0\,\frac{m}{s}\right)^2 + \left(4.0\,\frac{m}{s}\right)^2} = \sqrt{25.0\,\frac{m^2}{s^2}} = 5.0\,\frac{m}{s}$$

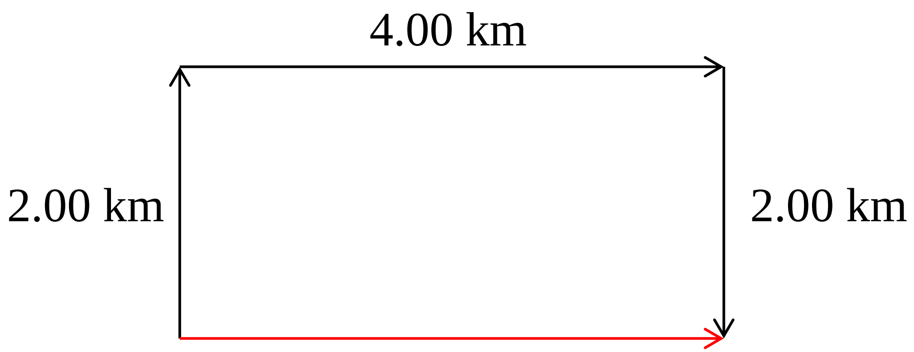
$$\tan(\theta) = \frac{v_{J,B}}{v_{B,S}} \qquad \theta = \tan^{-1}\left(\frac{v_{J,B}}{v_{B,S}}\right) = \tan^{-1}\left(\frac{4.0\,\frac{m}{s}}{9.0\,\frac{m}{s}}\right) = 24°$$

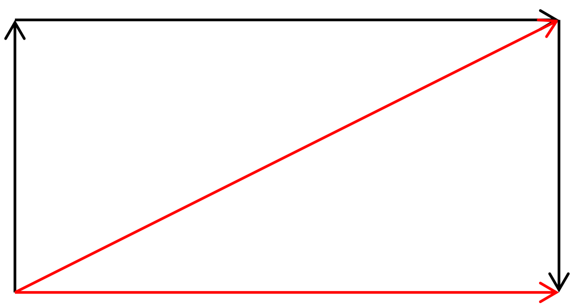
Therefore he ran 5.0 m/s South 24 degrees East

- When we're adding vectors we can draw them and connect them tail-to-tip. The sum of the vectors now forms a triangle from tail-to-tip.



- This is really what we did last week with displacement.





2. 2D Uniform Motion Wrapup

- In 2D Motion Displacement is the sum of displacement vectors
  - $\Delta\vec{d}_{\text{total}} = \Delta\overrightarrow{d_1} + \Delta\vec{d}_2$
- Average velocity is just the ratio of total displacement per total time
  - $\vec{v}_{av} = \frac{\Delta\vec{d}_{\text{total}}}{\Delta t}$
- All motion happens within some frame of reference (usually the earth)
- $\vec{v}_{AC} = \vec{v}_{AB} + \vec{v}_{BC}$

2. 2D Motion Concept Questions

1. Can the size of an objects displacement be bigger than it’s total distance travelled? Why?
2. Can the total difference travelled by an object be bigger than the size of its displacement? Why?
3. How does $\vec{v}_{AB}$ compare to $\vec{v}_{BA}$?
4. A wind is blowing from the west at an airport with an east-west runway. Should airplanes be travelling east or west as they approach the runway for landing? Why?

1 Motion Review – Crashing Stuff

- A train heads south from Toronto at 5:00 pm going a constant 100.0 km/h. A train heads north from Aldershot at 5:00 pm going a constant 98.00 km/h. The distance from the Aldershot station to the Toronto station is 87.5 km. If the track switcher malfunctions so that the two trains are on the same track how long does it take for them to collide?

$$\vec{v}_{AG} = 98.00\,\frac{\mathrm{km}}{\mathrm{h}}\,[\mathrm{N}]$$

$$\vec{v}_{TG} = 100.0\,\frac{km}{h}\,[S] = -100.0\,\frac{km}{h}\,[N]$$

$$\Delta\vec{d}_A = 87.5\ km\ [North] = -\Delta\vec{d}_T$$

$$\vec{v}_{av} = \frac{\Delta\vec{d}}{\Delta t}$$

$$\vec{v}_{AC} = \vec{v}_{AB} + \vec{v}_{BC}$$

$$\vec{v}_{AT} = \vec{v}_{AG} + \vec{v}_{GT} = \vec{v}_{AG} - \vec{v}_{TG}$$

$$\vec{v}_{AT} = 98.00\,\frac{km}{h}\,[N] - \left(-100.0\,\frac{km}{h}\,[N]\right)$$

$$\vec{v}_{AT} = 198.0\,\frac{km}{h}\,[N]$$

$$\vec{v}_{AT} = \frac{\Delta\vec{d}_A}{\Delta t} \rightarrow \Delta t = \frac{\Delta\vec{d}_A}{\vec{v}_{AT}} = \frac{87.5\ km\ [N]}{198.0\,\frac{km}{h}\,[N]} = 0.4419\ hr$$

$$= 26.52\ min$$

Therefore after 26.52 minutes the trains collided.

3. Uniform Acceleration

- In your own words explain acceleration. Then try explaining it terms of our new physics vocabulary (time, velocity, speed, displacement, distance, etc.)
- Try explaining what negative acceleration is.
- Uniform velocity was when velocity stayed the same. Any change in velocity is called an *acceleration.*
- This includes:
  - Pushing the gas pedal in your car
  - Pushing the break pedal in your car
  - Turning the steering wheel in your car
- If that change in velocity is *constant* while it occurs, it is called uniform acceleration
- E.g. Breaking for a stop sign

Aside:

Position → Velocity → Acceleration → Jerk → Snap → Crackle → Pop

3. Uniform Acceleration

- Recall: Δ means “change in” so $\Delta \mathrm{t} = \mathrm{t_f} - \mathrm{t_i}$
- In the same way we can talk about the “change in” a speed: $\Delta v = v_f - v_i$
- Or even a change in velocity: $\Delta \vec{v} = \vec{v}_f - \vec{v}_i$
- Average velocity was given by: $\vec{v}_{av} = \frac{\Delta \vec{d}}{\Delta t}$
- Average acceleration is given by: $\vec{a}_{av} = \frac{\Delta \vec{v}}{\Delta t}$
- What are the units of acceleration?

3. Uniform Acceleration – Example

- A motorbike starting from rest and undergoing uniform acceleration reaches a velocity of 21.0 m/s [N] in 8.4 s. Find its average acceleration.

$$\vec{v}_f = 21.0\frac{m}{s}[N]$$
$$\vec{v}_i = 0$$
$$\Delta t = 8.4\ s$$

$$\vec{a}_{av} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t} = \frac{21.0\frac{m}{s}[N] - 0}{8.4\ s} = 2.5\frac{m}{s^2}\ [N]$$

$$\vec{a}_{av} = ?\frac{m}{s^2}$$

$$\vec{a}_{av} = \frac{\Delta\vec{v}}{\Delta t}$$

Therefore the bike underwent an acceleration of 2.5 m/s^2 to the North.

3. Uniform Acceleration – Example

- A plane uniformly accelerates $-14.7\ \frac{m}{s^2}\ [S]$ while landing on a North-South landing strip. If the entire landing took 3.5 s from the time the plane touched down what was the touchdown velocity? (Assuming the plane was travelling south, and ended up at rest.)

$$\vec{v}_f = 0$$
$$\vec{a}_{av} = -14.7\frac{m}{s^2}[S]$$
$$\Delta t = 3.5\ s$$

$$\vec{v}_i = ?\frac{m}{s}\ [S]$$

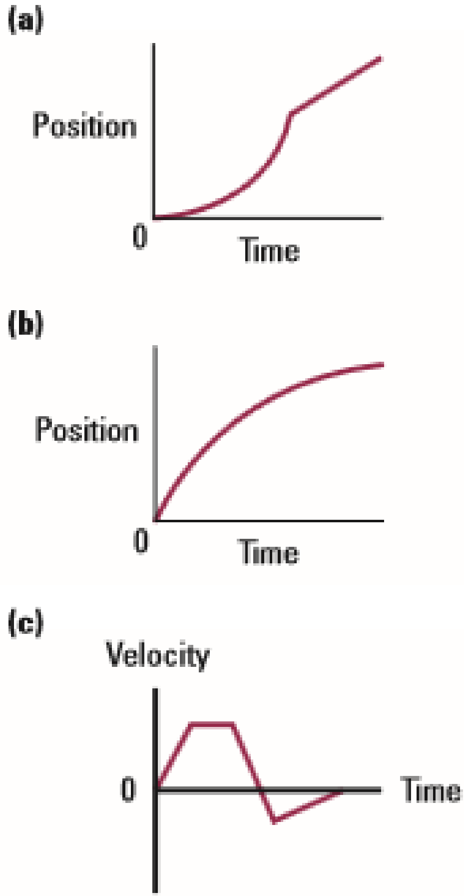
$$\vec{a}_{av} = \frac{\Delta\vec{v}}{\Delta t}$$

$$\vec{a}_{av} = \frac{\Delta\vec{v}}{\Delta t} \rightarrow \Delta\vec{v} = \vec{a}_{av}\,\Delta t$$
$$\vec{v}_f - \vec{v}_i = \vec{a}_{av}\,\Delta t$$
$$\vec{v}_i = -\,\vec{a}_{av}\Delta t$$
$$\vec{v}_i = -\left(-14.7\frac{\mathrm{m}}{s^2}[\mathrm{S}]\right)(3.5\ s)$$
$$\vec{v}_i = 51.45\frac{m}{s}[\mathrm{S}]$$

Therefore the plane touched down with a velocity of 51.5 m/s to the South.

3. Uniform Acceleration Concepts

- Rewrite the average acceleration equation for the following:
  - Final Velocity
  - Time interval
- Describe the motion in each graph using our physics-vocabulary (positive acceleration, negative acceleration, velocity, etc.)
- Can something have an eastward velocity but a westward acceleration? If so describe a situation in which this occurs. If not explain why not.
- Pilots and astronauts undergo very high accelerations. Why can this be problematic for them?



3. Uniform Acceleration

Questions?

4. Acceleration near the Earth's surface

- On Earth things fall.
  - Demonstration
- For the next unit we will assume there is no such thing as air resistance.
- Galileo showed that (ignoring air) the acceleration of falling objects is constant.
  - Demonstration
- As long as you stay near the Earth's surface the acceleration due to gravity is $9.80\frac{m}{s^2}\ [Down]$
  - $\vec{g}$
- So we can model this as a constant acceleration

4. Acceleration due to Gravity Example

- A stone is thrown from a bridge upwards at 4.0 m/s. Determine the stone's velocity after 2.2 s. Neglect air resistance.

$$\vec{v}_i = 4.0\frac{m}{s}\ [Up]$$
$$\Delta t = 2.2\ s$$
$$\vec{a} = 9.80\frac{m}{s^2}\ [Down]$$

$$\vec{v}_f = ?\frac{m}{s}$$

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} \rightarrow \vec{v}_f = \vec{v}_i + \vec{a}\Delta t$$

Let up be positive and down be negative.

$$v_f = v_i + a\ \Delta t$$
$$v_f = 4.0\frac{m}{s} - 9.80\frac{m}{s}(2.2\ s)$$
$$v_f = -17.56\frac{m}{s}$$

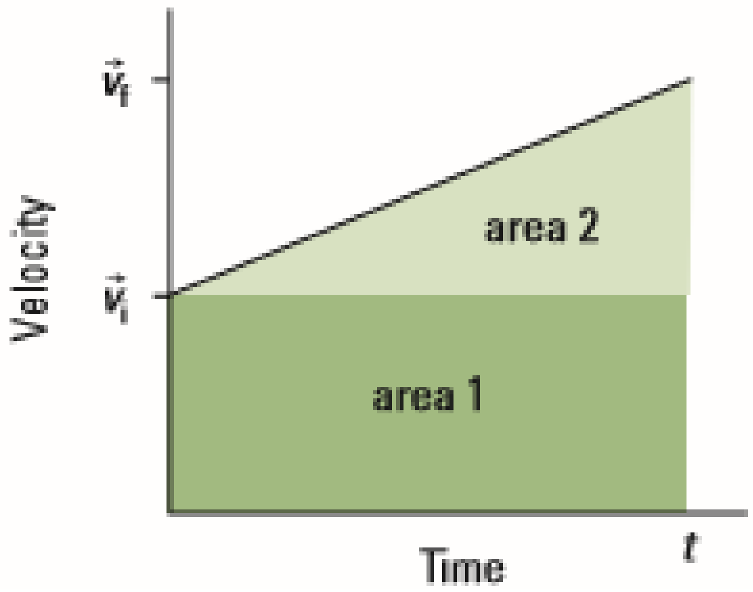
Therefore the stone's velocity after 2.2s was 18 m/s downwards.

4. Constant Acceleration Equations

- If We have a blackboard I will now derive these

- Calculus tells us that the displacement is the area underneath this line!

- Derivation time



1. $v_f = v_i + a\,\Delta t$
2. $\Delta d = v_{av}\,\Delta t$
3. $\Delta d = v_i \Delta t + \frac{1}{2} a\,\Delta t^2$
4. $v_f^2 = v_i^2 + 2\,a\,\Delta d$

4. Let's do some Acceleration Physics

- Starting from rest at t = 0.0 s, a car accelerates uniformly at 4.1 m/s^2 [S]. What is the car's displacement from its initial position after 5.0 s?

Let South be positive

$$\Delta t = 5.0s$$
$$v_i = 0$$
$$a = 4.1\frac{m}{s^2}$$

$$\Delta d = ?\,m$$

$$\Delta d = v_i \Delta t + \frac{1}{2} a\,\Delta t^2$$

$$\Delta d = 0\frac{m}{s}\,(5.0\ s) + \frac{1}{2}\left(4.1\frac{m}{s^2}\right)(5.0\ s)^2$$
$$= \frac{1}{2}\left(4.1\frac{m}{s^2}\right)(25.0\ s^2)$$
$$= 27.05\ m$$

Therefore the cars displacement was 27m South.

4. Let's do some Acceleration Physics

- A skier starting with an initial speed of 1.0 m/s accelerates uniformly downhill at 1.8 m/s^2 [fwd]. How long will it take the skier to reach a point 95 m [fwd] from the starting position?

Let fwd be positive

$$\Delta d = 95m$$
$$v_i = 1.0\ m/s$$
$$a = 1.8\frac{m}{s^2}$$

$$\Delta t = ?m$$

$$\Delta d = v_i \Delta t + \frac{1}{2} a\ \Delta t^2$$

$$0 = -\Delta d + v_i \Delta t + \frac{1}{2} a\ \Delta t^2$$

$$\therefore \Delta t = \frac{-v_i \pm \sqrt{v_i^2 - 4\left(\frac{1}{2}a\right)(-\Delta d)}}{2\left(\frac{1}{2}\ a\right)}$$

$$\Delta t = \frac{-\left(1.0\frac{m}{s}\right) \pm \sqrt{1.0\frac{m^2}{s^2} + 2\left(1.8\frac{m}{s^2}\right)(95\ m)}}{1.8\frac{m}{s^2}}$$

$$\Delta t = \frac{-1.0\frac{m}{s} \pm 18.5203\frac{m}{s}}{1.8\frac{m}{s^2}} = 9.7334\ s \text{ or } -10.8446\ s$$

Therefore it took the skier 9.7 s to get 95m fwd.

4. If it bleeds, we can kill it

- A man driving down a road at night sees the Predator in the road 48 m infront of him. Since the man new his sci-fi he sped up. If he accelerated 4.8 m/s² forward and 2.1 s later hit the Predator what was his final velocity?

Let forward be positive

$$\Delta d = 48m$$
$$\Delta t = 2.1\ s$$
$$a = 4.8\frac{m}{s^2}$$

$$v_f = ?\frac{m}{s}$$

$$\Delta d = v_i\Delta t + \frac{1}{2}a\ \Delta t^2$$
$$v_f = v_i + a\ \Delta t$$

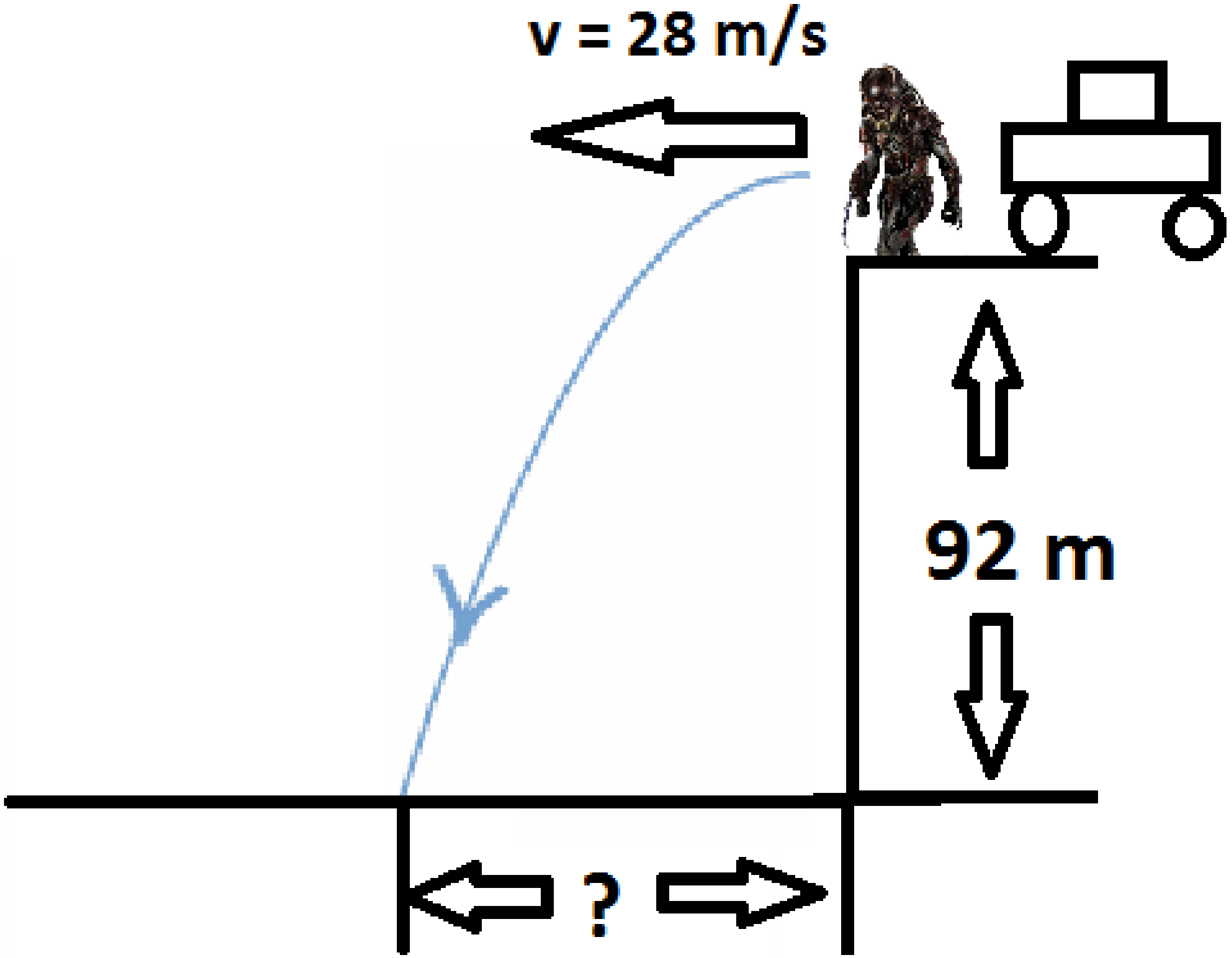
$$\Delta d = v_i\Delta t + \frac{1}{2}a\ \Delta t^2$$
$$v_i = \frac{\Delta d - \frac{1}{2}a\ \Delta t^2}{\Delta t} = \frac{\Delta d}{\Delta t} - \frac{1}{2}a\ \Delta t$$
$$v_i = \frac{48\ m}{2.1\ s} - \frac{1}{2}\left(4.8\frac{m}{s^2}\right)(2.1\ s)$$
$$v_i = 17.81714\frac{m}{s}$$

$$v_f = v_i + a\ \Delta t$$
$$v_f = 17.81714\frac{m}{s} + \left(4.8\frac{m}{s^2}\right)(2.1\ s)$$
$$v_f = 27.897\frac{m}{s}$$

Therefore he smashed into the Predator at a velocity of 28 m/s forward.

4. If it bleeds, we can kill it pt. 2

- After the collision the Predator flies off a cliff with the 28 m/s forward velocity. The cliff is 92 m high and has level ground at the bottom. How far forward does the predator land?



4. If it bleeds, we can kill it pt. 2

- After the collision the Predator flies off a cliff with the 28 m/s forward velocity. The cliff is 92 m high and has level ground at the bottom. How far forward does the predator land?

Let forward be positive
Let upward be positive

$$\Delta d_y = -92m$$
$$a_y = -9.80\frac{m}{s^2}$$
$$v_{i_x} = 28\frac{m}{s} = v_{f_x}$$
$$v_{i_y} = 0\frac{m}{s}$$

$$\Delta d_x = ?\,m$$

- Relevant Equations?

1. $v_f = v_i + a\,\Delta t$
2. $\Delta d = v_{av}\,\Delta t$
3. $\Delta d = v_i\Delta t + \frac{1}{2}a\,\Delta t^2$
4. $v_f^2 = v_i^2 + 2\,a\,\Delta d$

$$\Delta d_y = v_{i_y}\Delta t + \frac{1}{2}a_y\,\Delta t^2$$
$$\Delta d_y = \frac{1}{2}a_y\Delta t^2$$
$$\Delta t = \sqrt{2\frac{\Delta d_y}{a_y}} = \sqrt{2\,\frac{-92\,m}{-9.80\frac{m}{s^2}}} = 4.3330\,s$$

$$\Delta d_x = v_{av}\Delta t$$
$$\Delta d_x = v_{i_x}\Delta t = v_{f_x}\Delta t$$
$$\Delta d_x = 28\frac{m}{s}(4.3330\,s) = 121.326\,m$$

Therefore the predator landed 120 m forward from the base of the cliff.

4. Summarise

- Let's go over the parts of the previous problem
- Gunfire example
- Scalar vs. Vector
- What is the acceleration of an object at constant velocity
- What is constant acceleration?
- Two cars at the same stoplight accelerate from rest when the light turns green. Their motions are shown by the velocity-time graph.
  - After the motion has begun, at what time do the cars have the same velocity?
  - How could we find the displacement of one of the cars?