

**One-Dimensional Kinematics: Bonnie and Clyde (Solutions)**

In your new job, you are the technical advisor for the writers of a gangster movie about Bonnie and Clyde. In one scene Bonnie and Clyde try to flee from one state to another. If they get across the state line, they could evade capture, at least for a while until they become Federal fugitives. In the script, Bonnie is driving down the highway at 108 km/hr and passes a concealed police car that is 1 km from the state line. The instant Bonnie and Clyde pass the patrol car, the cop pulls onto the highway and accelerates at a constant rate of 2 m/s<sup>2</sup>. The writers want to know if they make it across the state line before the pursuing cop catches up with them.

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**Conceptual Analysis:**

- Since Bonnie and Clyde are traveling at a constant velocity and the cop is accelerating, at a certain place and time, the cop will overtake Bonnie and Clyde.

**Strategic Analysis:**

- Create two equations- one describing the motion of the accelerating cop and the other describing the motion of the constant velocity of Bonnie and Clyde.
- Pick one of two strategies to solve the problem. You can either
  - a) find the place where they meet to see if it is within the state line or after it, or
  - b) find the time it takes for each to reach the state line to see who reaches it first.
- Solve the two equations to find the place where the cop overtakes Bonnie and Clyde or who crosses the state line first, depending on which method you choose to use.

**Quantitative Analysis:**

Begin by labeling the given values:

$v_{BC}$  speed of Bonnie and Clyde

$d_{bord}$  distance from cop to border

$a_c$  acceleration of cop

We will be looking for either

$x_{BC}$  distance Bonnie and Clyde travel, and

$x_c$  distance the cop travels, which are equal where the two cars meet

or, using the other method, we will find

$t_{BC}$  the time it takes Bonnie and Clyde to reach the state line, and

$t_c$  the time it takes the cop to reach the state line

Next we can create equations to describe the motion of Bonnie and Clyde and the cop.

If we choose the initial time and position of the cop to be  $t_o = 0$  and  $x_o = 0$ , then we have the position of Bonnie and Clyde and the position of the cop after time  $t$  to be

$$\text{BC: } x_{BC} = v_{BC} * t$$

$$\text{Cop: } x_c = 1/2 * a_c * t^2$$

- Now you can choose between the two methods as you solve the equations.
- Let's start by solving for the place that they meet. When they meet  $x_{BC} = x_c$ . Knowing this we can solve:

$$v_{BC} * t = 1/2 * a_c * t^2$$

The time that they are in the same place,  $t_{same}$ , then, is

$$t_{same} = 2 * v_{BC} / a_c$$

Now we can find the place where they are at this time by plugging the time back into either of the position equations:

$$x_c = x_{BC} = 2 * v_{BC}^2 / a_c$$

- The other method is to find the time it takes each party to reach the state line.

$$\text{BC: } d_{bord} = v_{BC} * t_{BC}$$

$$\text{Cop: } d_{bord} = 1/2 * a_c * t_c^2$$

Then

$$t_{BC} = d_{bord} / v_{BC}$$

$$t_c = \text{sqrt} (2 * d_{bord} / a_c)$$

- We now have all of our solutions in terms of the given quantities. Let's insert the numbers so we can see whether or not Bonnie and Clyde escape. (Make sure that your units match in the equations as you solve them (km/hr or m/s).)

$$108 \left( \frac{\text{km}}{\text{h}} \right) \times 1000 \left( \frac{\text{m}}{\text{km}} \right) \times \left[ \frac{1}{3600 \left( \frac{\text{s}}{\text{h}} \right)} \right] = 30 \text{ m/s}$$

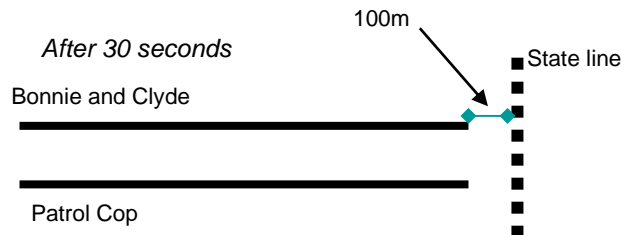
(Bonnie and Clyde's speed)

- Solving for the place where they meet:

$$x_c = x_{BC} = 2 * v_{BC}^2 / a_c = [2 * (30^2 \text{ m/s}^2)] / 2 \text{ m/s}^2 = 900 \text{ m}$$

You will find that the cop reaches Bonnie and Clyde 0.1 km before the state line.

Tell the writers that the patrol cop will catch them.



- Solving for the time it takes each to reach the state line:

$$t_{BC} = d_{bord} / v_{BC} = 1000 \text{ m} / (30 \text{ m/s}) = 33.3 \text{ s}$$

$$t_c = \text{sqrt} (2 * d_{bord} / a_c) = \text{sqrt} [2 * 1000 \text{ m} / (2 \text{ m/s}^2)] = 31.6 \text{ s}$$

You can see that the cop takes less time to reach the border, which means that he will overtake Bonnie and Clyde on this side of the state line.

Another way to solve the problem is to see where the cop is when Bonnie and Clyde cross the state line. You can insert their time into the cop's distance equation. If he is still on this side of the state line, they make it.

$$x_c = 1/2 * a_c * t^2 = 1/2 * (2 \text{ m/s}^2) * (33.3 \text{ s})^2 = 1111 \text{ m}$$

You will find that the cop goes 1111 m in the same time that it takes Bonnie and Clyde to go 1000 m to reach the state line; therefore, we know the cop must have passed Bonnie and Clyde some time before they reached the state line.

*After 33.3 seconds*

Bonnie and Clyde



Patrol Cop

■ State line



111m over state line



**Physics 211 Week 1**  
**One-Dimensional Kinematics: Catching the Train (Solutions)**  
(from Minnesota Cooperative Group Problems #16)

You are going to Chicago for the weekend and you decide to go first-class by taking the AmTrak train. Unfortunately, you are late finishing your mathematics exam, so you arrive late at the train station. You run as fast as you can, but just as you reach the platform your train departs, 30 meters ahead of you down the platform. You can run at a maximum speed of 8 m/s and the train is accelerating at 0.8 m/s<sup>2</sup>. You can run along the platform for 50 meters before a barrier prevents you from going further.

Will you catch your train?

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Conceptual Analysis:

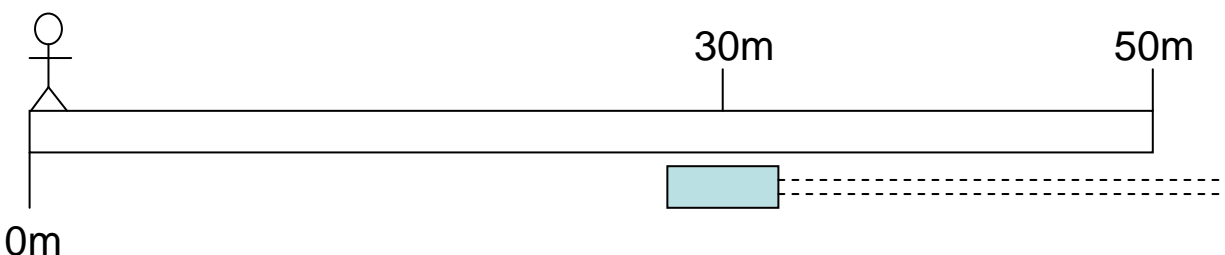
- The train moves with constant acceleration while you are running with a constant velocity.
- You will catch the train if you are at the same place at the same time before you reach the barrier.

Strategic Analysis:

- You want to find the time and the place that you and the train meet each other.
- We can use kinematics to find equations describing the motion of you and of the train.
- You will need to set up a way of measuring distance that is consistent for the platform, you, and the train.

Quantitative Analysis:

- Label the given quantities:
  - $v_y$  your speed
  - $x_t$  initial position of the train
  - $a_t$  acceleration of the train
  - $x_p$  length of platform
- We are looking for
  - $x$  the position that you and the train occupy at the same time
- Set up distances. The following diagram is one way.



- The motion of the train can be described by:

$$x = x_0 + v_0 * t + 1/2 * a * t^2$$

inserting the values for the train:

$$x = x_t + 1/2 * (a_t) * t^2$$

- Your motion can be described by:

$$x = x_0 + v_0 * t + 1/2 * a * t^2$$

inserting your values:

$$x = v_y * t$$

- You now have two equations and two variables. You can utilize the quadratic formula to find two solutions.

$$t = x / v_y$$

$$x = x_t + 1/2 * (a_t) * (x / v_y)^2$$

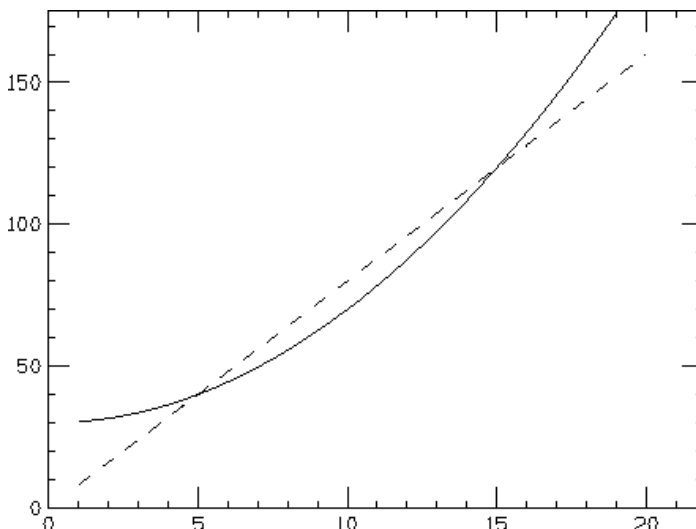
$$0 = [1/2 * (a_t / v_y^2)] * x^2 - x + x_t$$

$$X = \frac{1 \pm \sqrt{(-1)^2 - 4 * 1/2 * a_t / v_y^2 * x_t}}{2 * 1/2 * a_t / v_y^2}$$

$$X = \frac{1 \pm \sqrt{(-1)^2 - 4 * 1/2 * (0.8 \text{ m/s}^2) / (8 \text{ m/s})^2 * 30 \text{ m}}}{2 * 1/2 * (0.8 \text{ m/s}^2) / (8 \text{ m/s})^2}$$

$$x = 120 \text{ m or } 40 \text{ m}$$

- You can determine the amount of time it takes to reach the train by inserting your new distance back into one of your motion equations. You will catch the train after 5 seconds at 40m. If there were no barrier and the train continued to accelerate at a constant rate, it would pass you after 15s when you had run 120m.
- Because the motion of an accelerating object on a distance versus time graph is given by a quadratic and the constant velocity motion has a linear representation on a distance versus time graph, you and the train cross paths twice: once before the barrier and once after, as shown by the graph.



We are only concerned that you catch the train before the 50m barrier; we are not concerned with the solution at 15s, 120m.

You will catch the train after 5 seconds; 40m from your starting position (10m before the barrier).

## Physics 211 - Week 1

### One-Dimensional Kinematics: Falling Brick (Solutions)

As you are cycling to classes one day, you pass a construction site on Green Street for a new building and stop to watch for a few minutes. A crane is lifting a batch of bricks on a pallet to an upper floor of the building. Suddenly, a brick falls off the rising pallet. You clock the time it takes the brick to hit the ground at 2.5 seconds. The crane, fortunately, has height markings, and you see the brick fall off the pallet at a height of 22 meters above the ground. A falling brick, as we all know, can be dangerous, and you wonder how fast the brick was going when it hit the ground. Since you are taking physics, you quickly calculate the answer.

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The problem can be completed in two steps. We know the distance the brick falls, the acceleration due to gravity, and the time. We need to find the final speed so we will first need to know the initial velocity of the brick. The initial velocity is not zero! Since the brick is resting on the steadily rising pallet, it has an initial upward velocity not equal to zero. Once you find the initial velocity using a kinematics equation from the given information, you can then use the initial velocity you found, the known acceleration due to gravity, and time to find the final velocity of the brick before it hits the ground. You should obtain 21.065 m/s downward.

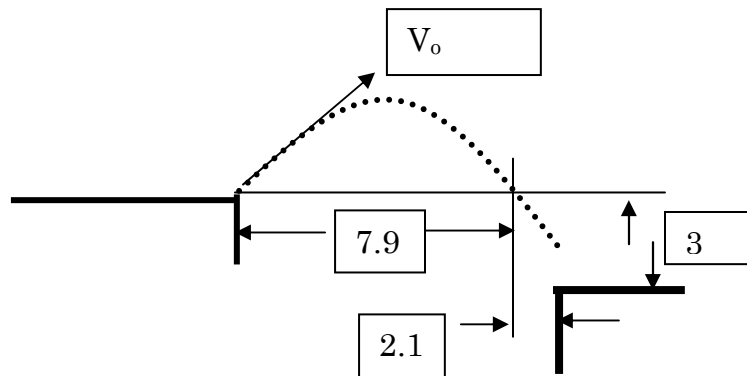
## Physics 211 - Week 1

### Two-Dimensional Kinematics: Escape from Burning Building (Solutions)

Your friend, a world-class long jumper, is trapped on the roof of a burning building. His only escape route is to jump to the roof of the next building. Fortunately for him, he is in telephone contact with you, a Physics 111 student, for advice on how to proceed. He has two options. He can jump to the next building by using the long-jump technique where he jumps at  $45^\circ$  to the horizontal. Or, he can take his chances by staying where he is in the hopes that the fire department will rescue him. You learn from the building engineers that the next building is 10 m away horizontally and the roof is 3 m below the roof of the burning building. You also know that his best long-jump distance is 7.9 m. What do you advise him to do?

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**A strategy:** Use the information on his best long-jump of 7.9 meters to compute his x component of velocity on a long-jump. Compute the extra flight time it will take him to sail the extra  $10 - 7.9 = 2.1$  meters to the next roof with the long-jump  $V_x$ . Compute the distance he will fall from height of the original roof during this extra flight time. If this distance exceeds 3 meters, he won't make the roof:



We begin by computing  $V_x$  which is the x component of the initial velocity. In the long-jump, described here, the initial velocity has equal x and y components ( $V_x = V_y$ ). At maximum height, the y component of velocity is zero.

$$\text{Thus } 0 = V_y - g t \text{ which means } t = V_y / g.$$

In a normal long jump, the total flight time is  $2t$  and the range covered is :  
**Dist=7.9 = (2V<sub>y</sub>/g) V<sub>x</sub> = 2 V<sub>x</sub><sup>2</sup>/g** Hence

$$V_x = \sqrt{2(d)g} = \sqrt{2(7.9\text{ m})(9.8\text{ m/s}^2)} = 6.22\text{ m/s}$$

The extra time for the jumper to cover the remaining 2.1 meters is

$$\Delta t = 2.1\text{ m}/6.22\text{ m/s} = 0.338\text{ s}$$

In that time, he will fall an additional distance of:

$$\Delta y = -\frac{1}{2} g \Delta t^2 - V_y \Delta t = -\frac{1}{2} 9.81\text{ m/s}^2 (0.338\text{ s})^2 - (6.22\text{ m/s})(0.338\text{ s}) = 2.663\text{ m}$$

He thus will still have some distance to fall once he has cleared the additional 2.1 meter horizontal distance.



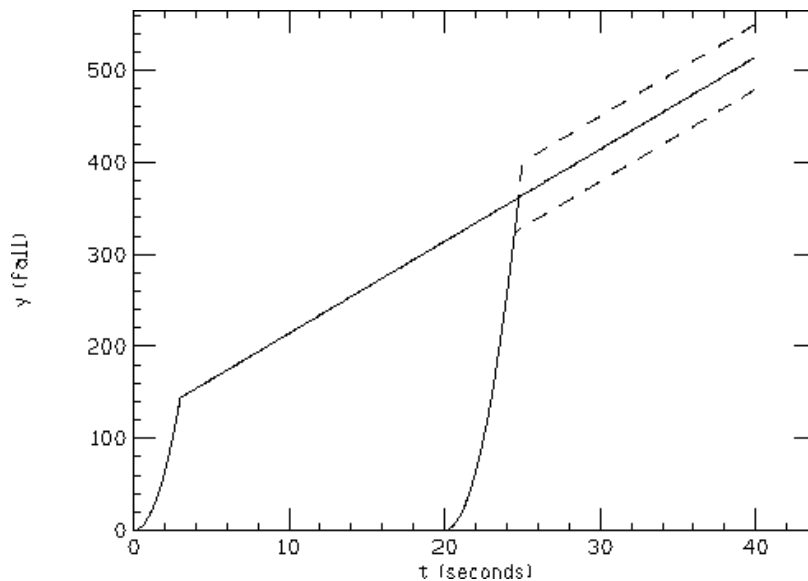
## Physics 211 - Week 1

### One-Dimensional Kinematics: Skydivers

The U of I Skydiving Club has asked you to plan a stunt for an air show. In this stunt, two skydivers will step out of opposite sides of a stationary hot air balloon 5,000 feet above the ground. The second skydiver will leave the balloon 20 seconds after the first skydiver, but you want them both to land on the ground at the same time. The show is planned for a day with no wind so you may assume all motion is vertical. To get a rough idea of the situation, assume that a skydiver will fall with a constant acceleration of  $32 \text{ ft/sec}^2$  before the parachute opens. As soon as the parachute is opened, the skydiver falls with a constant speed of  $10 \text{ ft/sec}$ . If the first skydiver, Sue, waits 3 seconds after stepping out of the balloon before opening her parachute, how long must the second skydiver, Joe, wait after leaving the balloon before opening his parachute?

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Joe and Sue will travel at the same constant velocity once both have opened their chutes. If Joe opens his chute too early, he will fall behind Sue; too late, he will fall in front of Sue; and at the time we are solving for, he will fall with Sue and they will arrive at the same time. The following graph shows these relationships. Sue's motion is on the left, while Joe's, on the right, starts 20 seconds after Sue began.



We can find Sue's total time that she falls, then we know that Joe's fall plus the 20 second delay is equal to Sue's time. We know the acceleration, initial and final velocity, as well as the total distance of the fall. After solving the necessary equations, you should obtain two solutions to the quadratic equation for time. The negative solution does not apply to our problem.

Joe should open his chute 4.75 seconds after he leaves the balloon in order to land at the same time as Sue.