Chapter 2

Chapter 2 Problems

1. What is the contact time between the puck and the stick in example ~~??~~? 2.5

$a_x = 495\ m/s^2 \quad v_{x0} = 0 \quad v_x = 24.6\ m/s$

$$a_x = \frac{\Delta v_x}{\Delta t} \longrightarrow \Delta t = \frac{\Delta v_x}{a_x} = \frac{24.6\ m/s - 0}{495\ m/s^2}$$

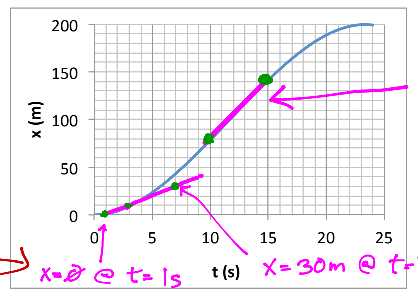
$$= 0.05\ s = 50\ ms$$

2. In figure 2.1, a runner's position is plotted as a function of time.
(a) Graphically estimate her velocity at t=3 seconds.
(b) For the whole run, what is her average speed, in m/s?
(c) On two grids, roughly sketch her speed as a function of time and her acceleration as a function of time. Include numbers on the axes.
(d) Is this run near Olympic standards?

a) slope $= V_x$

$$= \frac{30\,m - \emptyset\,m}{7s - 1s}$$

$$= 5\ m/s$$



x=Ø @ t=1s

x=30m @ t=7s

slope in middle of race:

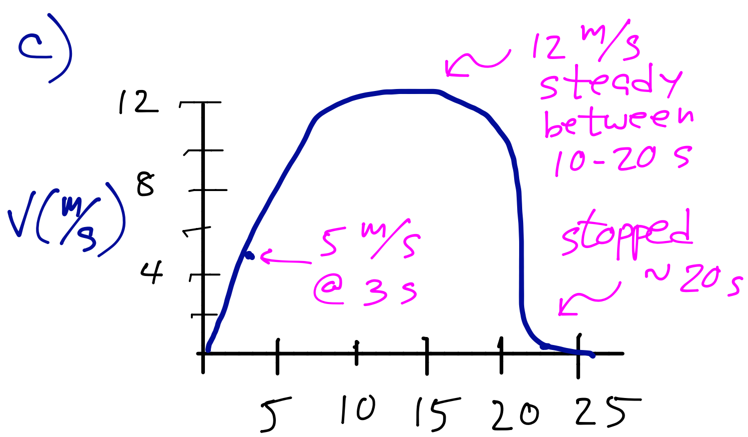
$$= \frac{140m - 80m}{15s - 10s}$$

$$= 12\ m/s$$

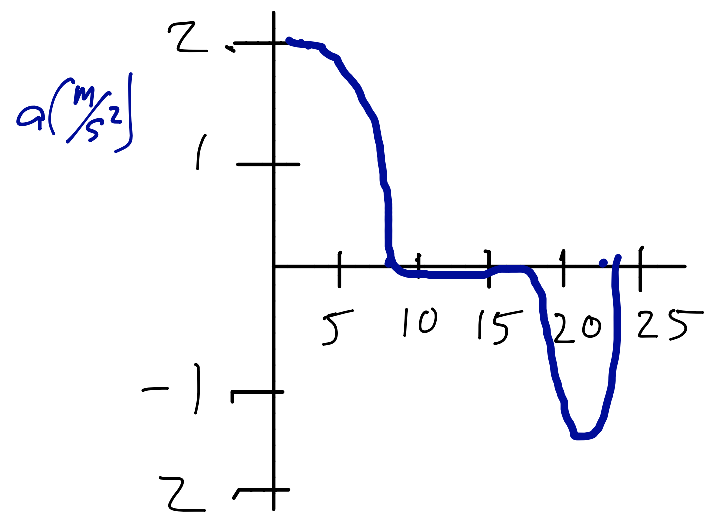
Figure 2.1: Problem 2.

b) $\overline{V_x} = \frac{\Delta x}{\Delta t} = \frac{200\,m}{25\,s} = 8\ m/s$

c)



slope ~ 2 m/s²



d) her time of ~ 23 sec is near Olympic standards

3. A baseball is thrown straight up with a velocity of 30 m/s. Indicating both the magnitude and direction of the velocity...
   a) what is the ball's velocity two seconds after being thrown?
   b) 4 seconds after being thrown?

$V_{oy} = 30\,m/s \qquad a_y = -9.8\,m/s^2$

a) $v_y = V_{oy} + a_y \Delta t = 30\,m/s + (-9.8\,m/s^2)(2\,s) = +10.4\,m/s$

$\rightarrow 10.4\,m/s$ up

b) $v_y = V_{oy} + a_y \Delta t = 30\,m/s + (-9.8\,m/s^2)(4\,s) = -9.2\,m/s$

$\rightarrow 9.2\,m/s$ down

4. A runner is moving at 5 m/s at t=2 s, and by t=5 s, she moves at 11 m/s in the same direction. What is her average acceleration?

$$\bar{a}_x = \frac{\Delta v_x}{\Delta t} = \frac{11\,\text{m/s} - 5\,\text{m/s}}{5\,\text{s} - 2\,\text{s}} = 2\,\text{m/s}^2$$

5. A lot of confusion about "floating" comes from the fact that a big jumper spends so much time near the very peak of his jump.
   a) If a basketball player jumps 36 inches straight up, for how long is he in the air?
   b) For how long is he within 9 inches of the top of his jump?
   c) What fraction of the time is he in the top 9″?

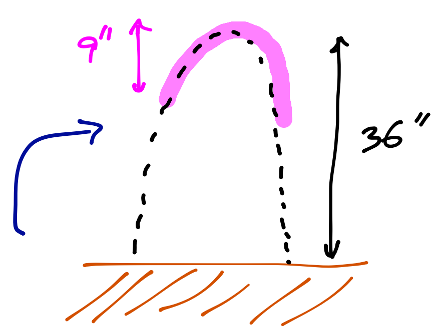
a) hangtime: $h = 36 \text{ in} = 3 \text{ ft}$

$$T_{hang} = 2\sqrt{\frac{2h}{g}} = 2\sqrt{\frac{2(3\text{ ft})}{32\text{ ft/s}^2}} = 0.866\text{ s}$$

b) easiest way: consider the time it takes to fall 9 inches, and double that. (it's also the same as T_{hang} for 9 inches, but that's not always obvious to students)

$$T_{fall} = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2\cdot 0.75\text{ ft}}{32\text{ ft/s}^2}} = 0.2165\text{ s}$$

$\Longrightarrow$ 0.433 s spent in top 9″



c) fraction of entire jump time spent in top 9″:

$$\frac{0.433\text{ s}}{0.866\text{ s}} = 50\%$$

6. L.A. Dodgers centerfielder Matt Kemp is one of the fastest players in baseball today, near the top of stolen base lists. He's been clocked at 22 mph, not too far from Bolt's peak speed, shown in figure ~~??~~ 12.7. Kemp rounds second and is racing towards third at 24 mph.
a) If he maintains a constant speed, how long does it take for him to cover the final 12 feet to third?
b) Of course, coming into 3rd base at full speed means that the runner will likely overrun the base. Therefore, the base coach signals Kemp to slide the final 12 feet. He does so, decelerating at a constant rate, coming to rest precisely on the base. What is the magnitude of his acceleration? How does this compare to the acceleration due to gravity?
c) By sliding, how much more time has Kemp taken to reach the bag? I.e. how long does it take him to cover the final 12′ when sliding, and how does that compare with your answer to part (a)?

a) $v_x = 22 \text{ mph} \cdot \dfrac{146.7 \text{ f/s}}{100 \text{ mph}} = 32.3 \text{ ft/s}$

$$\Delta t = \frac{\Delta x}{v_x} = \frac{12 \text{ ft}}{32.3 \text{ ft/s}} = 0.37 \text{ sec}$$

b) $v_x^2 = v_{0x}^2 + 2a_x \Delta x$

$$a_x = \frac{v_x^2 - v_{0x}^2}{2\Delta x} = \frac{\cancel{0} - (32.3 \text{ ft/s})^2}{2 \cdot (12 \text{ ft})} = -43.5 \text{ ft/s}^2$$

$$\frac{a_x}{g} = \frac{-43.5 \text{ f/s}^2}{32 \text{ ft/s}^2} = -1.36 \qquad a_x = 1.36\, g$$

c) $a_x = \dfrac{\Delta v_x}{\Delta t} \longrightarrow \Delta t = \dfrac{\Delta v_x}{a_x} = \dfrac{-32.3 \text{ ft/s}}{-43.5 \text{ ft/s}^2} = 0.74 \text{ s}$

Sliding doubles the time required to reach the bag.

7. A distance runner completes one mile in 5 minutes. What is his average velocity, in m/s?

$$V_x = \frac{\Delta x}{\Delta t} = \frac{1\ \text{mi}}{5\ \text{min}} \cdot \frac{1609\ \text{m}}{1\ \text{mi}} \cdot \frac{1\ \text{min}}{60\ \text{s}} = 5.36\ \text{m/s}$$

8. A Ferrari Scaglietti has an acceleration of 5.9 m/s^2, which we assume constant. How far down the track has it gone, 5 seconds after it's jumped off the starting line?

$$\Delta x = v_{0x}\Delta t + \frac{1}{2}a_x \Delta t^2 = \cancel{0} + \frac{1}{2}(5.9\,\text{m/s}^2)(5\,\text{s})^2$$

$$= 73.75\ \text{m}$$

9. When an object accelerates at 9.8 m/s^2 (or 32 ft/s^2), we say it accelerates with one "gee" (g). This is true whether the object is falling under gravity, or due to something else. Using the constant-acceleration approximation we've discussed in this chapter, how many "gee's" describe the following situations?
(a) Cedar Point's Top Thrill Dragster (an awesome ride, by the way): According to the park, it goes 0-120 mph in 3.8 seconds on the horizontal track, before turning up vertically.
(b) A football kickoff: The ball is initially at rest on the tee. After being in contact with the kicker's foot for only 8 ms, it leaves the kicker's foot at 85 ft/sec.

a) Top Thrill : $a = \frac{\Delta v}{\Delta t} = \frac{120 \text{ mph}}{3.8 s} \cdot \frac{44.7 \text{ m/s}}{100 \text{ mph}} = 14.1 \text{ m/s}^2$

$$\frac{a}{g} = \frac{14.1 \text{ m/s}^2}{9.8 \text{ m/s}^2} = 1.44 \rightarrow a = 1.44\ g$$

b) kickoff : $a = \frac{85 \text{ ft/s}}{0.008 s} = 10625 \text{ ft/s}^2$

$$\frac{a}{g} = \frac{10625 \text{ ft/s}^2}{32 \text{ ft/s}^2} = 332 \rightarrow a = 332\ g$$

10. On the left in figure 2.2 are four sketched graphs of position versus time.
(a) Which velocity-versus-time graph (on the right) corresponds with each position-versus-time graph?
(b) Which of the velocity-versus-time plot(s) could correspond to motion under a constant, non-zero acceleration?

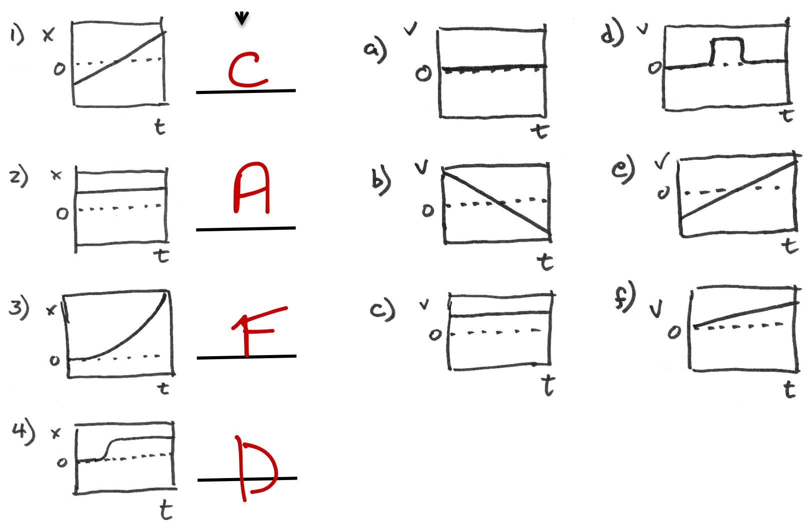


Figure 2.2: Problem 10.

b) const a: b, e, f

11. Unaware that you have taken a physics class, a major league pitcher claims that he can throw a baseball from the ground, straight up as high as the Empire State Building, which is 1250 feet tall.
(a) At what speed would he have to throw the ball, to accomplish this?
(b) Approximately how fast *can* a major league pitcher throw a ball?
(c) Using your answer from part (b), how high would the ball go, if thrown straight up?

a) $h = \frac{v_{0y}^2}{2g} \longrightarrow v_{0y} = \sqrt{2gh} = \sqrt{2\cdot(32\ ft/s^2)(1250\ ft)} = 283\ ft/s$

$= 283\ ft/s \times \frac{100\ mph}{146.7\ ft/s} = 193\ mph$

b) The best can hit about 100 mph $= 146.7\ ft/s$

c) $h = \frac{v_{0y}^2}{2g} = \frac{(146.7\ ft/s)^2}{2(32\ ft/s^2)} = 336\ ft$

12. There are many legends of basketball players with 2-second hang times. This would mean 1 second on the way up, and one second coming back down.
a) How high would his feet be above the floor, at the peak of the jump?
b) At what speed would the player come crashing back down onto the hard floor?
c) Is such a jump plausible?

a) $T_{hang} = 2\sqrt{\frac{2h}{g}} \longrightarrow h = \frac{T_{hang}^2\, g}{8} = \frac{(2s)^2 (32\, ft/s^2)}{8} = 16\text{ ft}$

b) $v = \frac{g T_{hang}}{2} = \frac{(32\, ft/s^2)(2s)}{2} = 32\, ft/s \times \frac{100\text{ mph}}{146.7\, ft/s} = 22\text{ mph}$

c) no.

13. Hockey players have to react fast in a face-off. If the ref throws down the puck from waist-level at 18 feet/sec, how long does it take to hit the ice? How does this compare to human reaction time?

$\Delta y \simeq -3$ ft (~ waist level)

$$v_y^2 = v_{0y}^2 - 2g\,\Delta y = \left(-18\ \text{ft/s}\right)^2 - 2\left(32\ \text{ft/s}^2\right)\left(-3\ \text{ft}\right) = 516\ \text{ft}^2/\text{s}^2$$

$$v_y = -22.7\ \text{ft/s}$$

$$a_y = -g = \frac{\Delta v_y}{\Delta t} \longrightarrow \Delta t = \frac{\Delta v_y}{-g} = \frac{-22.7\ \text{ft/s} - (-18\ \text{ft/s})}{-32\ \text{ft/s}^2}$$

$$= 0.147\ \text{s}$$

~ the same or a little larger than human reaction time (100 - 150 ms)

14. Denard Robinson has one of the fastest 40-yd times, with an average speed of 18.94 mph. As we said in section ~~??~~ 2.2, though, 40-yd times are often "hand-measured," and do not include human reaction time as track and field events do. If an additional 150 ms were added to Robinson's time, to account for reaction time, what would his average speed be, in mph?

$$\bar{v}_x = \frac{\Delta x}{\Delta t} \rightarrow \Delta t = \frac{\Delta x}{\bar{v}_x} = \frac{40\text{ yd}}{18.94\text{ mph}\cdot\frac{146.7\text{ ft/s}}{100\text{ mph}}\cdot\frac{1\text{ yd}}{3\text{ ft}}} = 4.319\text{ s}$$

reported ave speed

reported time

not accounting for reaction time

including reaction time: $\Delta t = 4.319\text{ s} + 0.150\text{ s} = 4.669\text{ s}$

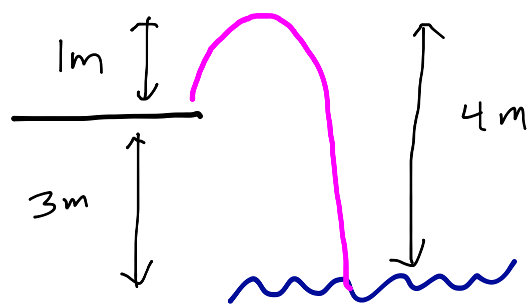
$$\Longrightarrow \bar{v}_x = \frac{120\text{ ft}}{4.669\text{ s}} = 25.70\ \frac{\text{ft}}{\text{s}} \times \frac{100\text{ mph}}{146.7\ \cancel{\text{ft/s}}} = 17.5\text{ mph}$$

15. In Olympic diving, the time one spends in the air determines the number of somersaults and twists the athlete can attempt. On the 3-meter springboard, the diver's c.m. first rises by 1 m, then falls to the water. On the 10-m platform dive, the diver more or less falls vertically, with very little initial rise.
a) According to your impression, which diver spends more time in the air?
b) How long is the 10-m platform diver in the air?
c) How long is the 3-m springboard diver in the air?

a) MY impression: springboard spends more time in the air

b) $T_{fall} = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2 \cdot 10\,m}{9.8\,m/s^2}} = 1.42\,s$

c) Take it in 2 parts



i) rise:

$T_{rise} = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2 \cdot 1m}{9.8\,m/s^2}} = 0.45\,s$

ii) fall

$T_{fall} = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2 \cdot (4m)}{g}} = 0.903\,s$

→ total: $\Delta t = 0.45\,s + 0.903\,s = 1.353\,s$

→ slightly longer on 10-m

initial impression that Δt is larger on springboard driven by fact that much of the motion there is at much lower speeds

16. Referring to table ~~??~~ 2.1 and figure ~~??~~ 2.1, what was Michael Phelps's average speed on the backstroke portion of his 2008 400-m medley? What was his average velocity on that portion?

leaving : 0:54.92

returning : 1:56.49

$\Delta t = 116.49\,s - 54.92\,s = 61.57\,s$

$$\text{speed} = \frac{\text{distance}}{\Delta t} = \frac{100\,m}{61.57\,s} = 1.62\ m/s$$

$$\bar{v}_x = \frac{\Delta x}{\Delta t} = 0 \quad (x_{begin} = x_{end})$$

17. Baseball players report that pitches are faster in Denver due to the lower air density there. But can drag really be a noticeable effect for such a short flight? In chapter **??**, we will be discussing the effects of air, but let's get a feel for these effects right now. Consider a 95 mph fastball thrown the 60′ 6″ from mound to plate. Don't worry about the vertical motion of the ball–we just care about horizontal.
a) If it travels at constant velocity, how long does it take to reach the plate?
b) Air drag tends to "decelerate" the ball at about 32 $\frac{\text{ft}}{\text{s}^2}$ (or 9.8 $\frac{\text{m}}{\text{s}^2}$), which is (rather coincidentally) one gee. If we account for drag how long does the ball's journey take?
c) To get a feeling of whether air drag really matters, compare the difference between your answers to (a) and (b), with the time a bat takes to cross the plate. Is the difference between your answers to (a) and (b) much larger than this time, much smaller than this time, about the same? To answer this question, you need to know that the bat is typically moving at about 70 mph as it crosses the plate and that the plate is about 1′ long.

a) $V = 95 \text{ mph} \cdot \dfrac{146.7 \text{ ft/s}}{100 \text{ mph}} = 139.4 \text{ ft/s}$

$$\Delta t = \frac{\Delta x}{v_x} = \frac{60.5 \text{ ft}}{139.4 \text{ ft/s}^2} = 0.43 \text{ s}$$

b) $v_x^2 = v_{x0}^2 + 2a_x \Delta x = (139.4 \text{ ft/s})^2 + 2(-32 \text{ ft/s}^2)(60.5 \text{ ft}) = 15{,}560 \text{ ft}^2/\text{s}^2$

$$v_x = 124.7 \text{ ft/s}$$

$$a_x = \frac{\Delta v_x}{\Delta t} \longrightarrow \Delta t = \frac{\Delta v_x}{a_x} = \frac{124.7 \text{ ft/s} - 139.4 \text{ ft/s}}{-32 \text{ ft/s}^2} = 0.459 \text{ s}$$

c) Difference due to air: $\Delta t_{\text{with air}} - \Delta t_{\text{without air}} = 0.459 \text{ s} - 0.430 \text{ s} = 0.029 \text{ s}$

Bat @ 70mph crossing 1ft plate: $\Delta t = \dfrac{1 \text{ ft}}{70 \text{ mph} \cdot \frac{146.7 \text{ ft/s}}{100 \text{ mph}}} = 0.01 \text{ s}$

$\Longrightarrow$ yes, timing diff due to air is significant relative to this scale

18. We will study aerodynamic forces in chapter **??**, but you already know that air drag will slow a table tennis ball speeding through the air. Professionals like J orgen Persson and fellow Swede Jan-Ove Waldner have had some epic matches. In one, Persson smashed a ball at 47 mph at his edge of the table. By the time it had crossed to the other side of the 9′ table, it had slowed to 40 mph.
a) In g's, what was the acceleration of the ball due to drag?
b) How long did the ball take, to cross the table?
c) How does your answer in (b) compare to typical human reaction time?
d) How much time was added due to the air drag? That is, how much more quickly would the ball have crossed the table, if it had continued at 47 mph on its entire trip?
e) In order to have enough time to react, Walder was not standing at the edge of the table, but 15 feet behind it. Assuming the same acceleration as you found in (a), how long does it take the ball to reach him, once Persson hit it?
f) Make motion graphcs: sketch the velocity and position of the ball as a function of time.

a) $V_{0x} = 47 \text{ mph} \cdot \dfrac{146.7 \text{ ft/s}}{100 \text{ mph}} = 68.95 \text{ ft/s}$

$V_x = 40 \text{ mph} \cdot \dfrac{146.7 \text{ ft/s}}{100 \text{ mph}} = 58.7 \text{ ft/s}$

$\Delta x = 9 \text{ ft}$

$$V_x^2 = V_{x0}^2 + 2a_x \Delta x \longrightarrow a_x = \frac{V_x^2 - V_{x0}^2}{2\Delta x} = \frac{(58.7 \text{ ft/s})^2 - (68.95 \text{ ft/s})^2}{2 \cdot (9 \text{ ft})}$$

$$= -72.7 \text{ ft/s}^2$$

$$\frac{|a_x|}{g} = \frac{72.7 \text{ ft/s}^2}{32 \text{ ft/s}^2} = 2.3 \Longrightarrow |a_x| = 2.3\,g$$

b) $$a_x = \frac{\Delta V_x}{\Delta t} \longrightarrow \Delta t = \frac{\Delta V_x}{a_x} = \frac{58.7 \text{ ft/s} - 68.95 \text{ ft/s}}{-72.7 \text{ ft/s}^2} = 0.14 \text{ s} = 140 \text{ ms}$$

c) 140 ms is about typical human reaction time

PROBLEM 18, cont'd

d) with no drag: $\Delta t = \frac{\Delta x}{v_x} = \frac{9\text{ ft}}{68.95\text{ ft/s}} = 0.13\text{ s}$

$\Longrightarrow$ 0.01 s = 10 ms was added due to drag

e) $\Delta x = 9\text{ ft} + 15\text{ ft} = 24\text{ ft}$

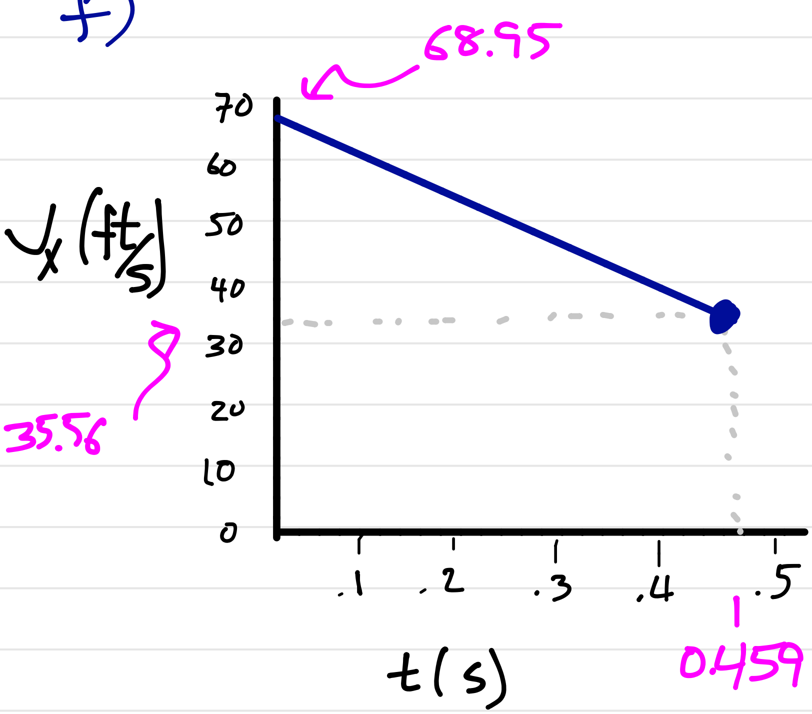
$$v_x^2 = v_{0x}^2 + 2a_x\Delta x$$

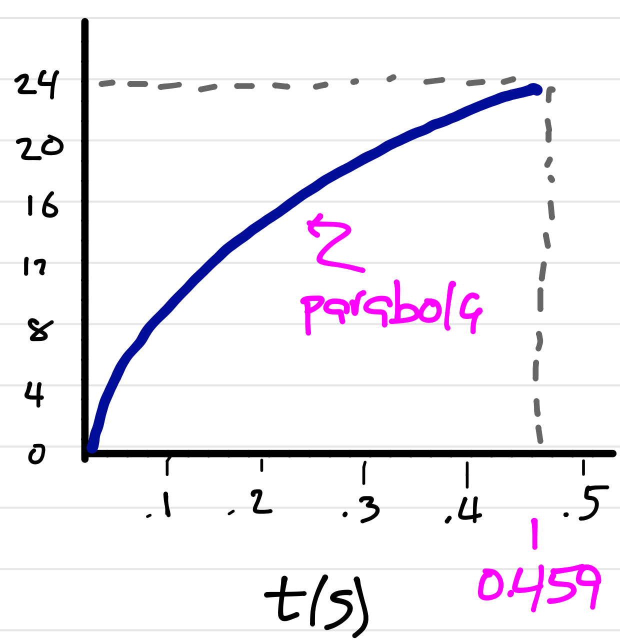
$$\longrightarrow v_x = \sqrt{(68.95\text{ ft/s})^2 + 2(-72.7\text{ ft/s}^2)(24\text{ ft})}$$

$$= 35.56\text{ ft/s}$$

$$\Delta t = \frac{\Delta v_x}{a_x} = \frac{35.56\text{ ft/s} - 68.95\text{ ft/s}}{-72.7\text{ ft/s}^2} = 0.459\text{ s}$$

f)





19. In November 2011, Miami Dolphins running back Reggie Bush was fined \$7500 for "excessive celebration" after a touchdown when he purposely slid 7 yd in the wet endzone, coming to rest right in front of a TV camera. He was moving at 25 ft/s (8.3 yd/s) when he began his slide.
a) What was his average acceleration?
b) How long (in seconds) did his slide last?

$\Delta x = 7\ \text{yd} = 21\ \text{ft}$

$v_{0x} = 25\ \text{ft/s}$

$v_x = \varnothing$ (stopped at end)

a) $v_x^2 = v_{0x}^2 + 2a_x \Delta x \longrightarrow a_x = \dfrac{v_x^2 - v_{0x}^2}{2\Delta x} = \dfrac{\varnothing^2 - (25\ \text{ft/s})^2}{2\cdot(21\ \text{ft})} = -14.9\ \text{ft/s}^2$

b) $\Delta t = \dfrac{\Delta v_x}{a_x} = \dfrac{-25\ \text{ft/s}}{-14.9\ \text{ft/s}^2} = 1.68\ \text{s}$

20. As clearly as you can, draw $x - t$ and $v - t$ graphs for a basketball player running the full length of the court– from one basket to another– at 19 mph for a break-away lay-up, then, over the course of 1 second, turning around and finally moving back to play defense under the hoop at 16 mph. You need to put numbers on all axes.

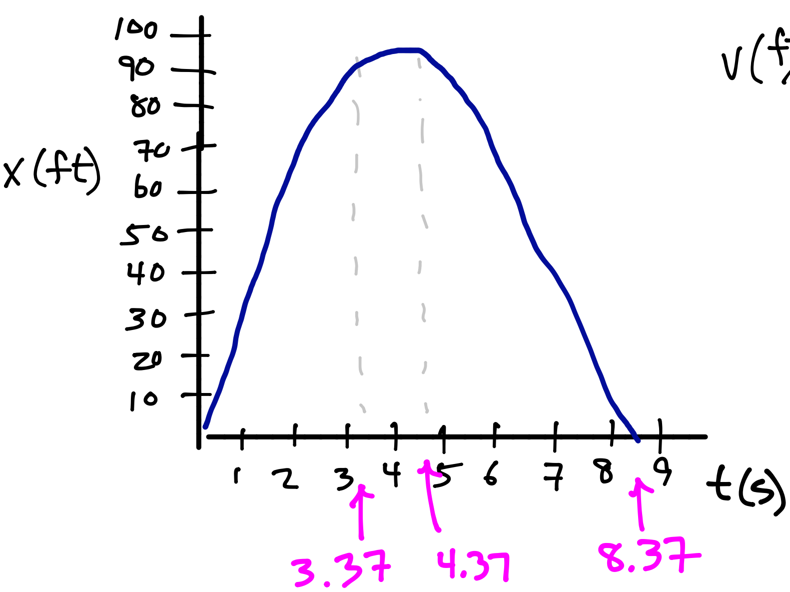
Length of NBA court: 94 ft (google)

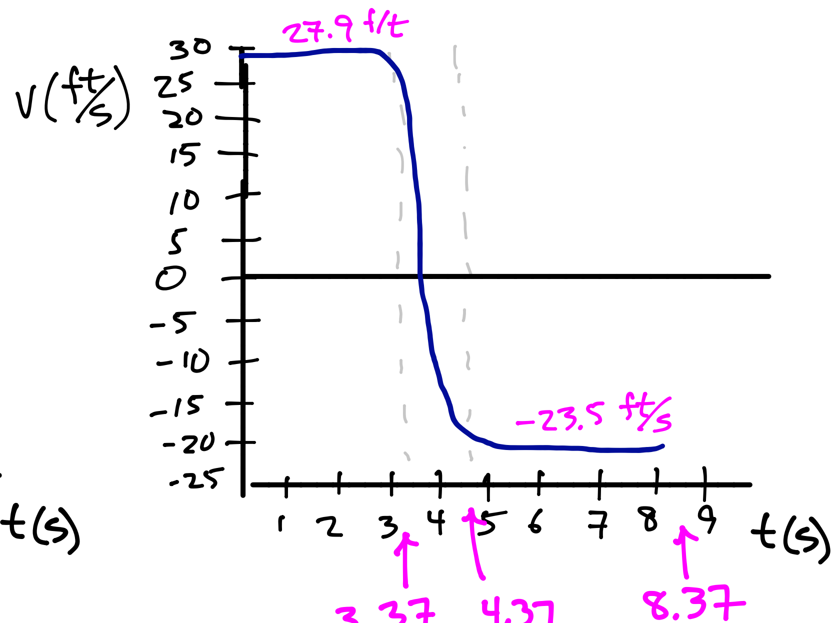
Running to one end: $v = 19 \text{ mph} \times \dfrac{147.6 \text{ ft/s}}{100 \text{ mph}} = 27.9 \text{ ft/s}$

$$\longrightarrow \Delta t = \frac{94 \text{ ft}}{27.9 \text{ ft/s}} = 3.37 \text{ sec}$$

Running back: $v = 16 \text{ mph} \times \dfrac{146.7 \text{ ft/s}}{100 \text{ mph}} = 23.5 \text{ ft/s}$

$$\longrightarrow \Delta t = \frac{94 \text{ ft}}{23.5 \text{ ft/s}} = 4 \text{ s}$$





21. In his record-setting sprint in Berlin, Usain Bolt's split time at the 20-m mark was 2.88 s.
a) Accounting for the fact that he didn't start moving until $t = 0.146$ s, due to reaction time, what was his average acceleration in this interval? Give your answer in $\frac{\text{m}}{\text{s}^2}$ and gee's.
b) How does this compare with a Ford Mustang, which goes from 0 to 60 mph in 5 s?

$$\Delta t_{\text{while running}} = 2.88\,\text{s} - 0.146\,\text{s} = 2.734\,\text{s}$$

a) $$\Delta x = \cancel{v_{0x}}^{\,0}\Delta t + \frac{1}{2}\bar{a}_x \Delta t^2$$

$$\longrightarrow \bar{a}_x = \frac{2\Delta x}{\Delta t^2} = \frac{2\cdot(20\,\text{m})}{(2.734\,\text{s})^2} = 5.35\,\text{m/s}^2$$

$$\frac{\bar{a}_x}{g} = \frac{5.35\,\text{m/s}^2}{9.8\,\text{m/s}^2} = 0.546 \rightarrow \bar{a}_x = 0.546\,g$$

b) Ford 0-60 mph in $\Delta t = 5\,\text{s}$

$$\Delta v_x = 60\,\text{mph}\cdot\frac{44.7\,\text{m/s}}{100\,\text{mph}} = 26.82\,\text{m/s}$$

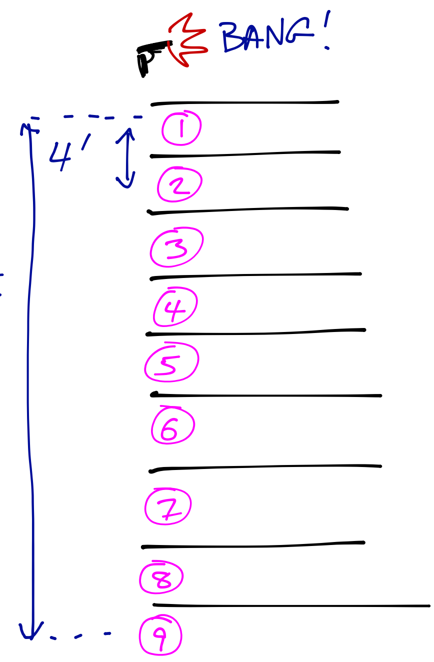
$$\Longrightarrow \bar{a}_x = \frac{\Delta v_x}{\Delta t} = \frac{26.82\,\text{m/s}}{5\,\text{s}} = 5.36\,\text{m/s}^2$$

identical accelerations!

22. If a race is begun with a starting pistol like the one in figure **??**, the runner nearest the gun might in principle have an advantage over his peers, since the sound reaches his ears before it reaches theirs. To prevent even this small unfairness, modern meets use a system of speakers behind the starting block of each competitor that sound simultaneously to start the race. But does it *really* matter? Let's see.
a) A track lane is 4′ wide. If the starter with the pistol stands on the inside of the track (next to lane 1), then how much sooner does the runner in lane 1 hear the report of a gun, as compared to the runner in lane 9?
b) How does this time difference compare with, say, the amount by which world records are broken?

a) time for sound to travel from lane 1 to lane 9

$8 \times 4\,\text{ft} = 32\,\text{ft}$



$$\Delta t = \frac{\Delta x}{v_x} = \frac{32\,\text{ft}}{1115\,\text{ft/s}} = 0.029\ \text{sec}$$

speed of sound

b) for the 100-m race, records typically broken by 0.02 - 0.03 s

$\Longrightarrow$ yes, this effect can matter!