Student Solutions Manual
for
Physics, 5^{th} Edition
by
Halliday, Resnick, and Krane
The Internet Short Edition

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This is the Internet Short Edition, made available to you because of a slight delay in the release of the print version. The entire book should be available for purchase at your bookstore by mid to late September.

Here are the solutions to approximately 25% of the exercises and problems. Enjoy your reading, but remember that reading my solutions will make a poor substitute for deriving your own.

I have tried to be very consistent in my units, showing them at all times. After the first few chapters, however, I begin to assume that you have mastered some of the more common conversions, such as minutes to seconds or years to hours.

I have usually respected the rules for significant figures in calculations throughout; usually, but not always, this meant only two or three significant figures are shown. When intermediate calculations are done I used the significant figures from those calculations, so expect rounding to have occurred. The answers in the back of the book are also written to the correct number of significant digits, but sometimes the results from intermediate calculations were left at whatever the calculator came up with. Consequently, we don't always agree, and neither will you.

Each question has been answered by at least two people, and our answers agree within the errors expected from rounding of significant figures. There are, however, a few exceptions, because part of this text was written in Tabakea's mwaneaba in the hills of Delainavesi on Viti Levu (*ti aki toki ni moi te nangkona n te tairiki*), and I wasn't able to communicate discrepancies. I don't think it was me that made the mistake; however, if you do find a mistake, and let me know, you might be entered in a drawing which could have as a grand prize a monetary award in excess of 10,000,000 nano-dollars! At the very least, I'll probably acknowledge the first sender of each significant contribution which is incorporated into any revision.

At times I may have been too complete in my descriptions. Forgive my verbosity.

I want to give special thanks to Tebanimarawa Stanley for scanning in what must have felt like thousands of pages of text and helping to convert this text to LaTeX; Andrea Katz for checking my math; Jessica Helms, Alison Hill, and Nicole Imhof for punching holes in the rough drafts and keeping track of the numerous handwritten notes on the various edits.

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Contents

Chapter 1

Measurement

E1-3 Multiply out the factors which make up a century. Note that each expression in parentheses is equal to one.

$$1 \text{ century} = 100 \text{ years} \left(\frac{365 \text{ days}}{1 \text{ year}}\right)\left(\frac{24 \text{ hours}}{1 \text{ day}}\right)\left(\frac{60 \text{ minutes}}{1 \text{ hour}}\right)$$

This gives 5.256×10^7 minutes in a century. The prefix *micro* means multiply by 10^{-6}, so a microcentury is $10^{-6} \times 5.256 \times 10^7$ or 52.56 minutes.

The percentage difference of x from y is defined as $(x - y)/y \times 100\%$. So the percentage difference from Fermi's approximation is $(2.56 \text{ min})/(50 \text{ min}) \times 100\%$ or 5.12%. Note that the percentage difference is dimensionless.

E1-7 The speed of a runner is given by the distance ran divided by the elapsed time. We don't know the actual distances, although they are probably very close to a mile. We'll assume, for convenience only, that the runner with the longer time ran *exactly* one mile. Let the speed of the runner with the shorter time be given by v_1, and call the distance actually ran by this runner d_1. Then $v_1 = d_1/t_1$. Remember, d_1 might not be a mile, it is instead 1 mile plus some error in measurement δ_1, which could be positive or negative. Similarly, $v_2 = d_2/t_2$ for the other runner, and $d_2 = 1$ mile.

We want to know when $v_1 > v_2$. Substitute our expressions for speed, and get $d_1/t_1 > d_2/t_2$. Rearrange, and $d_1/d_2 > t_1/t_2$ or $d_1/d_2 > 0.99937$. Remember to properly convert units when dividing the times! Then $d_1 > 0.99937 \text{ mile} \times (5280 \text{ feet}/1 \text{ mile})$ or $d_1 > 5276.7$ feet is the condition that the first runner was indeed faster. The first track can be no more than 3.3 feet too short to guarantee that the first runner was faster.

We originally assumed that the second runner ran on a perfectly measured track. You could solve the problem with the assumption that the first runner ran on the perfectly measured track, and find the error for the second runner. The answer will be slightly, but not significantly, different.

E1-9 First find the "logarithmic average" by

$$\begin{aligned} \log t_{\text{av}} &= \frac{1}{2}\left(\log(5\times10^{17})+\log(6\times10^{-15})\right), \\ &= \frac{1}{2}\log\left(5\times10^{17}\times6\times10^{-15}\right), \\ &= \frac{1}{2}\log 3000 = \log\left(\sqrt{3000}\right). \end{aligned}$$

Solve, and $t_{\text{av}} = 54.8$ seconds. This is about one minute. Note that we didn't need to specify *which* logarithm we were going to use, the answer would be the same with a base ten or a natural log! Not only that, you never needed to press the log button on your calculator to work out the answer.

E1-15 The volume of Antarctica is approximated by the area of the base time the height; the area of the base is the area of a semicircle. Then

$$V = Ah = \left(\frac{1}{2}\pi r^2\right)h,$$

where the factor of 1/2 comes from the *semi* in semicircle. The volume, keeping track of units, is

$$\begin{aligned} V &= \frac{1}{2}(3.14)(2000\times1000\text{ m})^2(3000\text{ m}) = 1.88\times10^{16}\text{ m}^3 \\ &= 1.88\times10^{16}\text{ m}^3\times\left(\frac{100\text{ cm}}{1\text{ m}}\right)^3 = 1.88\times10^{22}\text{ cm}^3. \end{aligned}$$

Note that we needed to convert *each* factor of a meter in the answer, and not just one of them. So we needed to cube the expression in the parenthesis in order to get the correct answer.

E1-19 One light-year is the distance traveled by light in one year. Since distance is speed times time, one light-year = $(3\times10^8\text{ m/s})\times(1\text{ year})$. Now we convert the units by multiplying through with appropriate factors of 1.

$$19,200\frac{\text{mi}}{\text{hr}}\left(\frac{\text{light-year}}{(3\times10^8\text{ m/s})\times(1\text{ year})}\right)\left(\frac{1609\text{ m}}{1\text{ mi}}\right)\left(\frac{1\text{ hr}}{3600\text{ s}}\right)\left(\frac{100\text{ year}}{1\text{ century}}\right),$$

which is equal to 0.00286 light-year/century.

E1-23 1.0 kg of hydrogen atoms is equal to the number of atoms times the mass of one atom. Table 1-6 shows that one hydrogen atom has a mass of $1.00783u$, where $u = 1.661\times10^{-27}$ kg. Then the number of atoms is given by $(1\text{ kg})/(1.00783\times1.661\times10^{-27}$ kg), or 5.974×10^{26} atoms.

E1-27 One sugar cube has a volume of 1.0 cm^3, so a mole of sugar cubes would have a volume of $N_A \times 1.0\ \text{cm}^3$, where N_A is the Avogadro constant. Since the volume of a cube is equal to the length cubed, $V = l^3$, then $l = \sqrt[3]{N_A}$ cm $= 8.4 \times 10^7$ cm. With an edge length equal to 844 kilometers, the top of such a cube would be higher than the orbit of the International Space Station.

E1-29 The definition of the meter was wavelengths per meter; the question asks for meters per wavelength, so we want to take the reciprocal. The definition is accurate to 9 figures, so the reciprocal should be written as $1/1,650,763.73 = 6.05780211 \times 10^{-7}$ m. A *nano* is 10^{-9}. Dividing our answer by 10^{-9} will then give 605.780211 nm.

E1-31 The easiest approach is to first solve Darcy's Law for K, and then substitute the known SI units for the other quantities. Then

$$K = \frac{VL}{AHt} \text{ has units of } \frac{(\text{m}^3)\,(\text{m})}{(\text{m}^2)\,(\text{m})\,(\text{s})}$$

which can be simplified to m/s.

P1-1 There are $24 \times 60 = 1440$ traditional minutes in a day, which is equivalent to the 1000 decimal minutes of metric clock. The conversion plan is then fairly straightforward

$$822.8 \text{ dec. min} \left(\frac{1440 \text{ trad. min}}{1000 \text{ dec. min}}\right) = 1184.8 \text{ trad. min.}$$

This is traditional minutes since midnight, the time in traditional hours can be found by dividing by 60 min/hr, the integer part of the quotient is the hours, while the remainder is the minutes. So the time is 19 hours, 45 minutes, which would be 7:45 pm.

P1-7 Break the problem down into parts. Some of the questions that need to be answered are (1) what is the surface area of a sand grain of radius 50 μm? (2) what is volume of this sand grain? It might be tempting to calculate the numerical value of each quantity, but it is more instructive to keep the expressions symbolic. Let the radius of the grain be given by r_g. Then the surface area of the grain is $A_g = 4\pi r_g^2$, and the volume is given by $V_g = (4/3)\pi r_g^3$.

If N grains of sand have a total surface area equal to that of a cube 1 m on a edge, then $NA_g = 6\ \text{m}^2$, since the cube has six sides each with an area of 1 m^2. The total volume V_t of this number of grains of sand is NV_g. We can eliminate N from these two expressions and get

$$V_t = NV_g = \frac{(6\ \text{m}^2)}{A_g} V_g = \frac{(6\ \text{m}^2) r_g}{3}$$

where the last step involved substituting the expressions for A_g and V_g. We haven't really started using numbers yet, and our expressions have simplified as a result. Now is, however, a good time to put in the numbers. Then $V_t = (2\ \text{m}^2)(50 \times 10^{-6}\ \text{m}) = 1 \times 10^{-4}\ \text{m}^3$.

All that is left is to find the mass. We were given that 2600 kg occupies a volume of 1 m^3, so the mass of the volume V_t is given by

$$1 \times 10^{-4}\ \text{m}^3 \left(\frac{2600\ \text{kg}}{1\ \text{m}^3}\right) = 0.26\ \text{kg},$$

about the mass of two quarter-pound hamburgers.

Chapter 2

Motion in One Dimension

E2-1 There are two ways of solving this particular problem.

Method I Add the vectors as is shown in Fig. 2-4. If $\vec{\mathbf{a}}$ has length $a = 4$ m and $\vec{\mathbf{b}}$ has length $b = 3$ m then the sum is given by $\vec{\mathbf{s}}$. The cosine law can be used to find the magnitude s of $\vec{\mathbf{s}}$,

$$s^2 = a^2 + b^2 - 2ab\cos\theta,$$

where θ is the angle between sides a and b in the figure. Put in the given numbers for each instance and solve for the angle.

(a) $(7\text{ m})^2 = (4\text{ m})^2 + (3\text{ m})^2 - 2(4\text{ m})(3\text{ m})\cos\theta$, so $\cos\theta = -1.0$, and $\theta = 180°$. This means that $\vec{\mathbf{a}}$ and $\vec{\mathbf{b}}$ are pointing in the same direction.

(b) $(1\text{ m})^2 = (4\text{ m})^2 + (3\text{ m})^2 - 2(4\text{ m})(3\text{ m})\cos\theta$, so $\cos\theta = 1.0$, and $\theta = 0°$. This means that $\vec{\mathbf{a}}$ and $\vec{\mathbf{b}}$ are pointing in the opposite direction.

(c) $(5\text{ m})^2 = (4\text{ m})^2 + (3\text{ m})^2 - 2(4\text{ m})(3\text{ m})\cos\theta$, so $\cos\theta = 0$, and $\theta = 90°$. This means that $\vec{\mathbf{a}}$ and $\vec{\mathbf{b}}$ are pointing at right angles to each other.

Method II You might have been able to just look at the numbers and "guess" the answers. This is a perfectly acceptable method, as long as you recognize the limitations and still verify your initial assumptions with concrete calculations. The verification is simple enough: for the vectors pointing in the same direction, add the magnitudes $(4 + 3 = 7)$; for vectors pointing in opposite directions, subtract the magnitudes $(|4-3| = 1)$; for vectors which meet at right angles, apply the Pythagoras relation $(4^2 + 3^2 = 5^2)$. If none of these approaches works then you need to solve the problem with the first method.

E2-5 We'll solve this problem in two steps. First, we find the components of the displacement vector along the north-south and east-west street system. Then we'll show that the sum of these components is actually the shortest distance.

The components are given by the trigonometry relations $O = H \sin\theta = (3.42\ \text{km}) \sin 35.0^\circ = 1.96$ km and $A = H \cos\theta = (3.42\ \text{km}) \cos 35.0^\circ = 2.80$ km. The stated angle is measured from the east-west axis, counter clockwise from east. So O is measured against the north-south axis, with north being positive; A is measured against east-west with east being positive.

Now we find the shortest distance by considering that the person can only walk east-west or north-south. Since her individual steps are displacement vectors which are only north-south or east-west, she must eventually take enough north-south steps to equal 1.96 km, and enough east-west steps to equal 2.80 km. Any individual step can only be along one or the other direction, so the minimum total will be 4.76 km.

E2-7 (a) In unit vector notation we need only add the components; $\vec{\mathbf{a}} + \vec{\mathbf{b}} = (5\hat{\mathbf{i}} + 3\hat{\mathbf{j}}) + (-3\hat{\mathbf{i}} + 2\hat{\mathbf{j}}) = (5-3)\hat{\mathbf{i}} + (3+2)\hat{\mathbf{j}} = 2\hat{\mathbf{i}} + 5\hat{\mathbf{j}}$.

(b) The magnitude of the sum is found from Pythagoras' theorem, because these components are at right angles. If we define $\vec{\mathbf{c}} = \vec{\mathbf{a}} + \vec{\mathbf{b}}$ and write the magnitude of $\vec{\mathbf{c}}$ as c, then $c = \sqrt{c_x^2 + c_y^2} = \sqrt{2^2 + 5^2} = 5.39$. The 2 and the 5 under the square root sign were the components found in part (a). We use those same components to find the direction, according to $\tan\theta = c_y/c_x$ which gives an angle of 68.2°, measured counterclockwise from the positive x-axis.

E2-13 Displacement vectors are given by the final position minus the initial position. Eventually we need to represent the position in each of the three positions where the minute hand is. Our axes will be chosen so that $\hat{\mathbf{i}}$ points toward 3 O'clock and $\hat{\mathbf{j}}$ points toward 12 O'clock.

(a) The two relevant positions are $\vec{\mathbf{r}}_{\text{i}} = (11.3\ \text{cm})\hat{\mathbf{i}}$ and $\vec{\mathbf{r}}_{\text{f}} = (11.3\ \text{cm})\hat{\mathbf{j}}$. The displacement in the interval is $\Delta\vec{\mathbf{r}} = \vec{\mathbf{r}}_{\text{f}} - \vec{\mathbf{r}}_{\text{i}}$; we can evaluate this expression by looking at the components, then

$$\begin{aligned} \Delta\vec{\mathbf{r}} &= \vec{\mathbf{r}}_{\text{f}} - \vec{\mathbf{r}}_{\text{i}} \\ &= (11.3\ \text{cm})\hat{\mathbf{j}} - (11.3\ \text{cm})\hat{\mathbf{i}} \\ &= -(11.3\ \text{cm})\hat{\mathbf{i}} + (11.3\ \text{cm})\hat{\mathbf{j}}, \end{aligned}$$

where in the last line we wrote the answer in the more traditional ordering of unit vectors. *But line 2 should be a perfectly adequate answer.*

(b) The two relevant positions are now $\vec{\mathbf{r}}_{\rm i} = (11.3\text{ cm})\hat{\mathbf{j}}$ and $\vec{\mathbf{r}}_{\rm f} = (-11.3\text{ cm})\hat{\mathbf{j}}$. Note that the 6 O'clock position for the minute hand has a negative sign. As before we can evaluate this expression by looking at the components, so

$$\begin{aligned}\Delta\vec{\mathbf{r}} &= \vec{\mathbf{r}}_{\rm f} - \vec{\mathbf{r}}_{\rm i}\\ &= (11.3\text{ cm})\hat{\mathbf{j}} - (-11.3\text{ cm})\hat{\mathbf{j}}\\ &= (22.6\text{ cm})\hat{\mathbf{j}}.\end{aligned}$$

There's a double negative in the second line that is often missed by students of introductory physics classes.

(c) The two relevant positions are now $\vec{\mathbf{r}}_{\rm i} = (-11.3\text{ cm})\hat{\mathbf{j}}$ and $\vec{\mathbf{r}}_{\rm f} = (-11.3\text{ cm})\hat{\mathbf{j}}$. As before we can evaluate this expression by looking at the components, so

$$\begin{aligned}\Delta\vec{\mathbf{r}} &= \vec{\mathbf{r}}_{\rm f} - \vec{\mathbf{r}}_{\rm i}\\ &= (-11.3\text{ cm})\hat{\mathbf{j}} - (-11.3\text{ cm})\hat{\mathbf{j}}\\ &= (0\text{ cm})\hat{\mathbf{j}}.\end{aligned}$$

The displacement is zero, since we have started and stopped in the same position!

E2-17 As always, remember to take the time derivatives *before* you substitute in for the time!

(a) Evaluate $\vec{\mathbf{r}}$ when $t = 2$ s.

$$\begin{aligned}\vec{\mathbf{r}} &= [(2\text{ m/s}^3)t^3 - (5\text{ m/s})t]\hat{\mathbf{i}} + [(6\text{ m}) - (7\text{ m/s}^4)t^4]\hat{\mathbf{j}}\\ &= [(2\text{ m/s}^3)(2\text{ s})^3 - (5\text{ m/s})(2\text{ s})]\hat{\mathbf{i}} + [(6\text{ m}) - (7\text{ m/s}^4)(2\text{ s})^4]\hat{\mathbf{j}}\\ &= [(16\text{ m}) - (10\text{ m})]\hat{\mathbf{i}} + [(6\text{ m}) - (112\text{ m})]\hat{\mathbf{j}}\\ &= [(6\text{ m})]\hat{\mathbf{i}} + [-(106\text{ m})]\hat{\mathbf{j}}.\end{aligned}$$

(b) Take the derivative of $\vec{\mathbf{r}}$ with respect to time, using the full form of $\vec{\mathbf{r}}$ from the first line of the equations above.

$$\begin{aligned}\vec{\mathbf{v}} = \frac{d\vec{\mathbf{r}}}{dt} &= [(2\text{ m/s}^3)3t^2 - (5\text{ m/s})]\hat{\mathbf{i}} + [-(7\text{ m/s}^4)4t^3]\hat{\mathbf{j}}\\ &= [(6\text{ m/s}^3)t^2 - (5\text{ m/s})]\hat{\mathbf{i}} + [-(28\text{ m/s}^4)t^3]\hat{\mathbf{j}}.\end{aligned}$$

Into this last expression we now evaluate $\vec{\mathbf{v}}(t = 2\text{ s})$ and get

$$\begin{aligned}\vec{\mathbf{v}} &= [(6\text{ m/s}^3)(2\text{ s})^2 - (5\text{ m/s})]\hat{\mathbf{i}} + [-(28\text{ m/s}^4)(2\text{ s})^3]\hat{\mathbf{j}}\\ &= [(24\text{ m/s}) - (5\text{ m/s})]\hat{\mathbf{i}} + [-(224\text{ m/s})]\hat{\mathbf{j}}\\ &= [(19\text{ m/s})]\hat{\mathbf{i}} + [-(224\text{ m/s})]\hat{\mathbf{j}},\end{aligned}$$

for the velocity $\vec{\mathbf{v}}$ when $t = 2$ s.

(c) We'll take the time derivative of $\vec{\mathbf{v}}$ to find $\vec{\mathbf{a}}$, making sure that we use the expression for $\vec{\mathbf{v}}$ before we substituted for t.

$$\begin{aligned}\vec{\mathbf{a}} = \frac{d\vec{\mathbf{v}}}{dt} &= [(6 \text{ m/s}^3)2t]\hat{\mathbf{i}} + [-(28 \text{ m/s}^4)3t^2]\hat{\mathbf{j}}\\ &= [(12 \text{ m/s}^3)t]\hat{\mathbf{i}} + [-(84 \text{ m/s}^4)t^2]\hat{\mathbf{j}}.\end{aligned}$$

Into this last expression we now evaluate $\vec{\mathbf{a}}(t = 2 \text{ s})$ and get

$$\begin{aligned}\vec{\mathbf{a}} &= [(12 \text{ m/s}^3)(2 \text{ s})]\hat{\mathbf{i}} + [-(84 \text{ m/s}^4)(2\ 2)^2]\hat{\mathbf{j}}\\ &= [(24 \text{ m/s}^2)]\hat{\mathbf{i}} + [-(336 \text{ m/s}^2)]\hat{\mathbf{j}}.\end{aligned}$$

However tempting it might be, it makes no physical sense to compare the acceleration with either the velocity or position at $t = 2$ s, or any other time, except to maybe note that one or more quantities might be zero.

E2-21 For the record, *Namulevu* and *Vanuavinaka* are perfectly good words in some language. See if your instructor will give you extra credit for translating the meaning. Of course, knowing the language would help, but *au na sega ni tukuna vei kemuni!*

Let the actual flight time, as measured by the passengers, be T. There is some time difference between the two cities, call it ΔT = Namulevu time - Los Angeles time. The ΔT will be positive if Namulevu is east of Los Angeles. The time in Los Angeles can then be found from the time in Namulevu by subtracting ΔT.

The actual time of flight from Los Angeles to Namulevu is then the difference between when the plane lands (LA times) and when the plane takes off (LA time):

$$\begin{aligned}T &= (18{:}50 - \Delta T) - (12{:}50)\\ &= 6{:}00 - \Delta T,\end{aligned}$$

where we have written times in 24 hour format to avoid the AM/PM issue. The return flight time can be found from

$$\begin{aligned}T &= (18{:}50) - (1{:}50 - \Delta T)\\ &= 17{:}00 + \Delta T,\end{aligned}$$

where we have again changed to LA time for the purpose of the calculation.

Now we just need to solve the two equations and two unknowns. The way we have written it makes it easier to solve for ΔT first by setting the two expressions for T equal to each other:

$$\begin{aligned}17{:}00 + \Delta T &= 6{:}00 - \Delta T\\ 2\Delta T &= 6{:}00 - 17{:}00\\ \Delta T &= -5{:}30,\end{aligned}$$

and yes, there are a number of places in the world with time zones that differ by half an hour. Since this is a negative number, Namulevu is located *west* of Los Angeles.

(a) Choose either the outbound or the inbound flight to find T. If we choose the outbound flight, $T = 6{:}00 - \Delta T = 11 : 30$, or eleven and a half hours. We've already found the time difference, so we move straight to (c).

(c) The distance traveled by the plane is given by $d = vt = (520$ mi/hr$)(11.5$ hr$) = 5980$ mi. We'll draw a circle around Los Angeles with a radius of 5980 mi, and then we look for where it intersects with longitudes that would belong to a time zone ΔT away from Los Angeles. Since the Earth rotates once every 24 hours and there are 360 longitude degrees, then each hour corresponds to 15 longitude degrees, and then Namulevu must be located approximately $15^\circ \times 5.5 = 83^\circ$ west of Los Angeles, or at about longitude 160 east. The location on the globe is then latitude 5°, in the vicinity of Vanuatu.

When this exercise was originally typeset the times for the outbound and the inbound flights were inadvertently switched. I suppose that we could blame this on the airlines; nonetheless, when the answers were prepared for the back of the book the reversed numbers put Namulevu *east* of Los Angeles. That would put it in either the North Atlantic or Brazil.

E2-25 Speed is distance traveled divided by time taken; this is equivalent to the inverse of the slope of the line in Fig. 2-32. The line appears to pass through the origin and through the point (1600 km, 80×10^6 y), so the speed is $v = 1600$ km$/80 \times 10^6$ y$= 2 \times 10^{-5}$ km/y. The answer requests units of centimeters per year, so we convert units by

$$v = 2 \times 10^{-5}\text{km/y} \left(\frac{1000 \text{ m}}{1 \text{ km}}\right)\left(\frac{100 \text{ cm}}{1 \text{ m}}\right) = 2 \text{ cm/y}$$

E2-29 Don't fall into the trap of assuming that the average speed is the average of the speeds. We instead need to go back to the definition: speed is distance traveled divided by time taken. It might look as if there isn't enough information to solve this problem, since we weren't given the distance or the time. We can solve the problem, however, with some algebra. Let $v_1 = 40$ km/hr be the speed up the hill, t_1 be the time taken, and d_1 be the distance traveled in that time. We similarly define $v_2 = 60$ km/hr for the down hill trip, as well as t_2 and d_2. Note that $d_2 = d_1$, because the car drove down the same hill it drove up.

Now for the algebra. $v_1 = d_1/t_1$ or $t_1 = d_1/v_1$; $v_2 = d_2/t_2$ or $t_2 = d_2/v_2$. The *average* speed will be $v_{\text{av}} = d/t$, where d total distance and t is the total time. But the total distance is $d_1 + d_2 = 2d_1$ because the up distance is same as the down distance. The total time t is just the sum of t_1 and t_2, so

$$\begin{aligned} v_{\text{av}} &= \frac{d}{t} \\ &= \frac{2d_1}{t_1 + t_2} \end{aligned}$$

$$
\begin{aligned}
&= \frac{2d_1}{d_1/v_1 + d_2/v_2} \\
&= \frac{2}{1/v_1 + 1/v_2},
\end{aligned}
$$

where in the last line we used $d_2 = d_1$ and then factored out d_1. So, as expected, we never needed to know the height of the hill, or the time. The last expression looks a little nasty; but we can take the reciprocal of both sides to get a simpler looking expression

$$\frac{2}{v_{\rm av}} = \frac{1}{v_1} + \frac{1}{v_2}.$$

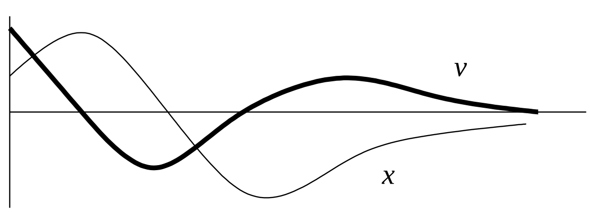
In either case, the average speed is 48 km/hr.

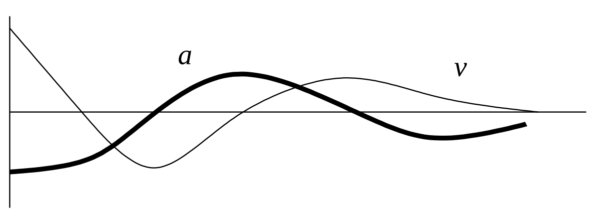
E2-33 The initial velocity is $\vec{\mathbf{v}}_{\rm i} = (18 \text{ m/s})\hat{\mathbf{i}}$, the final velocity is $\vec{\mathbf{v}}_{\rm f} = (-30 \text{ m/s})\hat{\mathbf{i}}$. Negative signs *can't* be ignored in this problem; acceleration and velocity are both vectors and require some indication of direction. The average acceleration is then

$$\vec{\mathbf{a}}_{\rm av} = \frac{\Delta\vec{\mathbf{v}}}{\Delta t} = \frac{\vec{\mathbf{v}}_{\rm f} - \vec{\mathbf{v}}_{\rm i}}{\Delta t} = \frac{(-30 \text{ m/s})\hat{\mathbf{i}} - (18 \text{ m/s})\hat{\mathbf{i}}}{2.4 \text{ s}},$$

which gives $\vec{\mathbf{a}}_{\rm av} = (-20.0 \text{ m/s}^2)\hat{\mathbf{i}}$.

E2-37 When the displacement-time graph is at a maximum or minimum the velocity should be zero, meaning the velocity-time graph will pass through the time axis. There are no straight line segments in the distance-time graph, so there are no constant velocity segments for the velocity-time graph.





E2-41 This one dimensional, constant acceleration problem states the acceleration, $a_x = 9.8 \text{ m/s}^2$, the initial velocity, $v_{0x} = 0$, and the final velocity $v_x = 0.1c = 3.0 \times 10^7$ m/s.

(a) We are then asked for the time it will take for the space ship to acquire the final velocity. Applying Eq. 2-26,

$$\begin{aligned} v_x &= v_{0x} + a_x t, \\ (3.0 \times 10^7 \text{ m/s}) &= (0) + (9.8 \text{ m/s}^2)t, \\ 3.1 \times 10^6 \text{ s} &= t. \end{aligned}$$

This is about one month. Although accelerations of this magnitude are well within the capability of modern technology, we are unable to sustain such accelerations for even several hours, much less a month.

(b) If, however, the acceleration could be sustained, how far would the rocket ship travel? We apply Eq. 2-28 using an initial position of $x_0 = 0$,

$$\begin{aligned} x &= x_0 + v_{0x} + \frac{1}{2} a_x t^2, \\ x &= (0) + (0) + \frac{1}{2}(9.8 \text{ m/s}^2)(3.1 \times 10^6 \text{ s})^2, \\ x &= 4.7 \times 10^{13} \text{ m}. \end{aligned}$$

This distance is 8000 times farther than Pluto, and considerably farther than any spacecraft has ever traveled; it is also about the same distance that light travels in a day and a half, and only a small fraction of the distance to the nearest star to the sun.

E2-45 Given in this problem are the initial velocity, $v_{0x} = 1020$ km/hr; the final velocity, $v_x = 0$, and the time taken to stop the sled, $t = 1.4$ s. It will be easier to solve the problem if we change the units for the initial velocity,

$$v_{0x} = 1020 \frac{\text{km}}{\text{hr}} \left(\frac{1000 \text{ m}}{\text{km}} \right) \left(\frac{\text{hr}}{3600 \text{ s}} \right) = 283 \frac{\text{m}}{\text{s}},$$

and then applying Eq. 2-26,

$$\begin{aligned} v_x &= v_{0x} + a_x t, \\ (0) &= (283 \text{ m/s}) + a_x(1.4 \text{ s}), \\ -202 \text{ m/s}^2 &= a_x. \end{aligned}$$

The negative sign reflects the fact that the rocket sled is slowing down. The problem asks for this in terms of g, so

$$-202 \text{ m/s}^2 \left(\frac{g}{9.8 \text{ m/s}^2} \right) = 21g.$$

E2-49 The problem will be somewhat easier if the units are consistent, so we'll write the maximum speed as

$$1000\frac{\text{ft}}{\text{min}}\left(\frac{\text{min}}{60\text{ s}}\right) = 16.7\,\frac{\text{ft}}{\text{s}}.$$

(a) The distance traveled during acceleration can't be found directly from the information given (although some textbooks do introduce a *third* kinematic relationship in addition to Eq. 2-26 and Eq. 2-28 that would make this possible.) We can, however, easily find the time required for the acceleration from Eq. 2-26,

$$\begin{aligned} v_x &= v_{0x} + a_x t, \\ (16.7\text{ ft/s}) &= (0) + (4.00\text{ ft/s}^2)t, \\ 4.18\text{ s} &= t. \end{aligned}$$

And from this and Eq 2-28 we can find the distance

$$\begin{aligned} x &= x_0 + v_{0x} + \frac{1}{2}a_x t^2, \\ x &= (0) + (0) + \frac{1}{2}(4.00\text{ ft/s}^2)(4.18\text{ s})^2, \\ x &= 34.9\text{ ft}. \end{aligned}$$

This is considerably less than 624 ft; this means that through most of the journey the elevator is traveling at the maximum speed.

(b) The motion of the elevator is divided into three parts: acceleration from rest, constant speed motion, and deceleration to a stop. The total distance is given at 624 ft and in part (a) we found the distance covered during acceleration was 34.9 ft. By symmetry, the distance traveled during deceleration should also be 34.9 ft, but it would be good practice to verify this last assumption with calculations. The distance traveled at constant speed is then $(624 - 34.9 - 34.9)$ ft = 554 ft. The time required for the constant speed portion of the trip is found from Eq. 2-22, rewritten as

$$\Delta t = \frac{\Delta x}{v} = \frac{554\text{ ft}}{16.7\text{ ft/s}} = 33.2\text{ s}.$$

The total time for the trip is the sum of times for the three parts: accelerating (4.18 s), constant speed (33.2 s), and decelerating (4.18 s). The total is 41.6 seconds.

E2-53 The initial velocity of the "dropped" wrench would be zero. The acceleration would be 9.8 m/s^2. Although we can orient our coordinate system any way we want, I choose vertical to be along the y axis with up as positive, which is the convention of Eq. 2-29 and Eq. 2-30. Note that Eq. 2-29 is equivalent to Eq. 2-26, we could have used either. The same is true for Eq. 2-30 and Eq. 2-28.

It turns out that it is much easier to solve part (b) before solving part (a). So that's what we'll do.

(b) We solve Eq. 2-29 for the time of the fall.

$$\begin{aligned} v_y &= v_{0y} - gt, \\ (-24.0\text{ m/s}) &= (0) - (9.8\text{ m/s}^2)t, \\ 2.45\text{ s} &= t. \end{aligned}$$

We manually insert the minus sign for the final velocity because the object is moving *down*. We don't insert an extra minus sign in front of the 9.8 because it is explicit in Eq. 2-29; we would have, however, needed to insert it if we had used Eq. 2-26.

(a) Now we can easily use Eq. 2-30 to find the height from which the wrench fell.

$$\begin{aligned} y &= y_0 + v_{0y}t - \frac{1}{2}gt^2, \\ (0) &= y_0 + (0)(2.45\text{ s}) - \frac{1}{2}(9.8\text{ m/s}^2)(2.45\text{ s})^2, \\ 0 &= y_0 - 29.4\text{ m} \end{aligned}$$

We have set $y = 0$ to correspond to the final position of the wrench: on the ground. This results in an initial position of $y_0 = 29.4$ m; it is positive because the wrench was dropped from a point *above* where it landed.

We could instead have chosen the initial point to correspond to $y_0 = 0$, where we make our measurements from the point where the wrench was dropped. If we do this, we find $y = -29.4$ m. The negative sign indicates that the wrench landed *below* the point from which it was dropped.

E2-57 Don't assume that 36.8 m corresponds to the highest point.

(a) Solve Eq. 2-30 for the initial velocity. Let the distances be measured from the ground so that $y_0 = 0$.

$$\begin{aligned} y &= y_0 + v_{0y}t - \frac{1}{2}gt^2, \\ (36.8\text{ m}) &= (0) + v_{0y}(2.25\text{ s}) - \frac{1}{2}(9.8\text{ m/s}^2)(2.25\text{ s})^2, \\ 36.8\text{ m} &= v_{0y}(2.25\text{ s}) - 24.8\text{ m}, \\ 27.4\text{ m/s} &= v_{0y}. \end{aligned}$$

(b) Solve Eq. 2-29 for the velocity, using the result from part (a).

$$\begin{aligned} v_y &= v_{0y} - gt, \\ v_y &= (27.4 \text{ m/s}) - (9.8 \text{ m/s}^2)(2.25 \text{ s}), \\ v_y &= 5.4 \text{ m/s}. \end{aligned}$$

(c) We need to solve Eq. 2-30 to find the height to which the ball rises, but we don't know how long it takes to get there. So we first solve Eq. 2-29, because we do know the velocity at the highest point ($v_y = 0$).

$$\begin{aligned} v_y &= v_{0y} - gt, \\ (0) &= (27.4 \text{ m/s}) - (9.8 \text{ m/s}^2)t, \\ 2.8 \text{ s} &= t. \end{aligned}$$

And then we find the height to which the object rises,

$$\begin{aligned} y &= y_0 + v_{0y}t - \frac{1}{2}gt^2, \\ y &= (0) + (27.4 \text{ m/s})(2.8 \text{ s}) - \frac{1}{2}(9.8 \text{ m/s}^2)(2.8 \text{ s})^2, \\ y &= 38.3\text{m}. \end{aligned}$$

This is the height as measured from the ground; so the ball rises $38.3 - 36.8 = 1.5$ m above the point specified in the problem.

E2-61 The total time the pot is visible is 0.54 s; the pot is visible for 0.27 s on the way down. We'll define the initial position as the highest point and make our measurements from there. Then $y_0 = 0$ and $v_{0y} = 0$. Define t_1 to be the time at which the *falling* pot passes the top of the window y_1, then $t_2 = t_1 + 0.27$ s is the time the pot passes the bottom of the window $y_2 = y_1 - 1.1$ m. We have two equations we can write, both based on Eq. 2-30,

$$\begin{aligned} y_1 &= y_0 + v_{0y}t_1 - \frac{1}{2}gt_1^2, \\ y_1 &= (0) + (0)t_1 - \frac{1}{2}gt_1^2, \end{aligned}$$

and

$$\begin{aligned} y_2 &= y_0 + v_{0y}t_2 - \frac{1}{2}gt_2^2, \\ y_1 - 1.1 \text{ m} &= (0) + (0)t_2 - \frac{1}{2}g(t_1 + 0.27 \text{ s})^2, \end{aligned}$$

Isolate y_1 in this last equation and then set the two expressions equal to each other so that we can solve for t_1,

$$\begin{aligned}
-\frac{1}{2}gt_1^2 &= 1.1 \text{ m} - \frac{1}{2}g(t_1 + 0.27 \text{ s})^2, \\
-\frac{1}{2}gt_1^2 &= 1.1 \text{ m} - \frac{1}{2}g(t_1^2 + [0.54 \text{ s}]t_1 + 0.073 \text{ s}^2), \\
0 &= 1.1 \text{ m} - \frac{1}{2}g([0.54 \text{ s}]t_1 + 0.073 \text{ s}^2).
\end{aligned}$$

This last line can be directly solved to yield $t_1 = 0.28$ s as the time when the falling pot passes the top of the window. Use this value in the first equation above and we can find $y_1 = -\frac{1}{2}(9.8 \text{ m/s}^2)(0.28 \text{ s})^2 = -0.38$ m. The negative sign is because the top of the window is beneath the highest point, so the pot must have risen to 0.38 m above the top of the window.

P2-3 We align the coordinate system so that the origin corresponds to the starting position of the fly and that all positions inside the room are given by positive coordinates.

(a) The displacement vector can just be written,

$$\Delta\vec{\mathbf{r}} = (10 \text{ ft})\hat{\mathbf{i}} + (12 \text{ ft})\hat{\mathbf{j}} + (14 \text{ ft})\hat{\mathbf{k}}.$$

(b) The magnitude of the displacement vector is the square root of the sum of the squares of the components, a generalization of Pythagoras' Theorem. $|\Delta\vec{\mathbf{r}}| = \sqrt{10^2 + 12^2 + 14^2}$ ft$=$ 21 ft.

(c) The straight line distance between two points is the shortest possible distance, so the length of the path taken by the fly must be greater than or equal to 21 ft.

(d) If the fly walks it will need to cross two faces. The shortest path will be the diagonal across these two faces. If the lengths of sides of the room are l_1, l_2, and l_3, then the diagonal length across two faces will be given by

$$\sqrt{(l_1 + l_2)^2 + l_3^2},$$

where we want to choose the l_i from the set of 10 ft, 12 ft, and 14 ft that will minimize the length. Trial and error works (there are only three possibilities), or we can reason out that we want the squares to be minimal, in particular we want the largest square to be the smallest possible. This will happen if $l_1 = 10$ ft, $l_2 = 12$ ft, and $l_3 = 14$. Then the minimal distance the fly would *walk* is 26 ft.

P2-7 (a) Don't try to calculate this by brute force, unless you are a glutton for punishment. Assume the bird has no size, the trains have some separation, and the bird is just leaving one of the trains. The bird will be able to fly from one train to the other *before* the two trains collide, regardless of how close together the trains are. After doing so, the bird is now on the other train, the trains are still separated, so once again the bird can fly between the trains before they collide. This process can be repeated every time the bird touches one of the trains, so the bird will make an infinite number of trips between the trains. But it makes this infinite number of trips in a finite time, because eventually the trains do collide.

(b) The trains collide in the middle; using a simple application of distance equals speed times time we find that the trains collide after (51 km)/(34 km/hr) = 1.5 hr. The bird was flying with constant speed this entire time, so the distance flown by the bird is (58 km/hr)(1.5 hr) = 87 km. This apparent paradox of an infinite number of trips summing to a finite length was investigated by Zeno quite a number of years ago.

P2-11 (a) The average velocity is displacement divided by change in time,

$$v_{\text{av}} = \frac{(2.0\text{ m/s}^3)(2.0\text{ s})^3 - (2.0\text{ m/s}^3)(1.0\text{ s})^3}{(2.0\text{ s}) - (1.0\text{ s})} = \frac{14.0\text{ m}}{1.0\text{ s}} = 14.0\text{ m/s}.$$

The average acceleration is the change in velocity. So we need an expression for the velocity, which is the time derivative of the position,

$$v = \frac{dx}{dt} = \frac{d}{dt}(2.0\text{ m/s}^3)t^3 = (6.0\text{ m/s}^3)t^2.$$

From this we find average acceleration

$$a_{\text{av}} = \frac{(6.0\text{ m/s}^3)(2.0\text{ s})^2 - (6.0\text{ m/s}^3)(1.0\text{ s})^2}{(2.0\text{ s}) - (1.0\text{ s})} = \frac{18.0\text{ m/s}}{1.0\text{ s}} = 18.0\text{ m/s}^2.$$

(b) The instantaneous velocities can be found directly from $v = (6.0\text{ m/s}^2)t^2$, so $v(2.0\text{ s}) = 24.0$ m/s and $v(1.0\text{ s}) = 6.0$ m/s. We can get an expression for the instantaneous acceleration by taking the time derivative of the velocity

$$a = \frac{dv}{dt} = \frac{d}{dt}(6.0\text{ m/s}^3)t^2 = (12.0\text{ m/s}^3)t.$$

Then the instantaneous accelerations are $a(2.0\text{ s}) = 24.0\text{ m/s}^2$ and $a(1.0\text{ s}) = 12.0$ m/s^2

(c) Since the motion is monotonic we expect the average quantities to be somewhere between the instantaneous values at the endpoints of the time interval. Indeed, that is the case.

P2-17 The runner covered a distance d_1 in a time interval t_1 during the acceleration phase and a distance d_2 in a time interval t_2 during the constant speed phase. Since the runner started from rest we know that the constant speed is given by $v = at_1$, where a is the runner's acceleration.

The distance covered during the acceleration phase is given by Eq. 2-28 with $v_{0x} = 0$,

$$d_1 = \frac{1}{2}at_1^2.$$

The distance covered during the constant speed phase can also be found from Eq. 2-28 except now with $a = 0$,

$$d_2 = vt_2 = at_1t_2.$$

We want to use these two expressions, along with $d_1 + d_2 = 100$ m and $t_2 = (12.2 \text{ s}) - t_1$, to get

$$\begin{aligned} 100 \text{ m} &= d_1 + d_2 = \frac{1}{2}at_1^2 + at_1(12.2 \text{ s} - t_1), \\ &= -\frac{1}{2}at_1^2 + a(12.2 \text{ s})t_1, \\ &= -(1.40 \text{ m/s}^2)t_1^2 + (34.2 \text{ m/s})t_1. \end{aligned}$$

This last expression is quadratic in t_1, and is solved to give $t_1 = 3.40\,\text{s}$ or $t_1 = 21.0\,\text{s}$. Since the race only lasted 12.2 s we can ignore the second answer.

(b) The distance traveled during the acceleration phase is then

$$d_1 = \frac{1}{2}at_1^2 = (1.40 \text{ m/s}^2)(3.40\,\text{s})^2 = 16.2\,\text{m}.$$

P2-21 The rocket travels a distance $d_1 = \frac{1}{2}at_1^2 = \frac{1}{2}(20 \text{ m/s}^2)(60 \text{ s})^2 = 36,000$ m during the acceleration phase; the rocket velocity at the end of the acceleration phase is $v = at = (20 \text{ m/s}^2)(60 \text{ s}) = 1200$ m/s. The second half of the trajectory can be found from Eqs. 2-29 and 2-30, with $y_0 = 36,000$ m and $v_{0y} = 1200$ m/s.

(a) The highest point of the trajectory occurs when $v_y = 0$, so we solve Eq. 2-29 for time.

$$\begin{aligned} v_y &= v_{0y} - gt, \\ (0) &= (1200 \text{ m/s}) - (9.8 \text{ m/s}^2)t, \\ 122 \text{ s} &= t. \end{aligned}$$

This time is used in Eq. 2-30 to find the height to which the rocket rises,

$$\begin{aligned} y &= y_0 + v_{0y}t - \frac{1}{2}gt^2, \\ &= (36000 \text{ m}) + (1200 \text{ m/s})(122\text{s}) - \frac{1}{2}(9.8 \text{ m/s}^2)(122 \text{ s})^2 = 110000 \text{ m}. \end{aligned}$$

(b) The easiest way to find the total time of flight is to solve Eq. 2-30 for the time when the rocket has returned to the ground. Then

$$\begin{aligned} y &= y_0 + v_{0y}t - \frac{1}{2}gt^2, \\ (0) &= (36000 \text{ m}) + (1200 \text{ m/s})t - \frac{1}{2}(9.8 \text{ m/s}^2)t^2. \end{aligned}$$

This quadratic expression has two solutions for t; one is negative so we don't need to worry about it, the other is $t = 270\,\text{s}$. This is the free-fall part of the problem, to find the total time we need to add on the 60 seconds of accelerated motion. The total time is then 330 seconds.

P2-25 This is a problem that is best solved backwards, then forwards. We want to find the deceleration of the woman. We know the distance through which she decelerated (18 in) and her final velocity (0), but not the time taken nor the initial velocity at the start of the deceleration phase. So neither Eq. 2-26 nor Eq. 2-28 is of much use. However, since her deceleration is assumed uniform, we could apply Eq. 2-27 to find her average velocity (if we knew her initial velocity), and then use Eq. 2-22 to find the time elapsed during deceleration since we know the distance, and then use Eq. 2-26 to find the acceleration. So all that we need to find is the initial velocity at the start of the deceleration phase.

But this initial velocity is the same as the final velocity at the end of the freely falling part of the motion. We would need to use Eq. 2-29 to find this final velocity, but we don't know the time to fall. However, we could get that time from Eq. 2-30, since we know the initial velocity at the start of the fall (0) and the distance through which she fell (144 ft). So now we are prepared to solve the problem. Since inches and feet are used throughout, I'm going to use $g = 32$ ft/s^2 for the acceleration of free-fall.

Now we reverse our approach and work forwards through the problem and find the time she fell from Eq. 2-30. I've written this equation a number of times in the past few pages, so I'll just substitute the variables in directly.

$$(0 \text{ ft}) = (144 \text{ ft}) + (0)t - \frac{1}{2}(32 \text{ ft/s}^2)t^2,$$

which is a simple quadratic with solutions $t = \pm 3.0$ s. Only the positive solution is of interest, since we assume she was falling forward in time. Use this time in Eq. 2-29 to find her speed when she hit the ventilator box,

$$v_y = (0) - (32 \text{ ft/s}^2)(3.0 \text{ s}) = -96 \text{ ft/s}.$$

This becomes the initial velocity for the deceleration motion, so her average speed during deceleration is given by Eq. 2-27,

$$v_{\text{av}}, y = \frac{1}{2}(v_y + v_{0y}) = \frac{1}{2}((0) + (-96 \text{ ft/s})) = -48 \text{ ft/s}.$$

This average speed, used with the distance of 18 in (1.5 ft), can be used to find the time of deceleration

$$v_{\text{av}}, y = \Delta y/\Delta t,$$

and putting numbers into the expression gives $\Delta t = 0.031$ s. We actually used $\Delta y = -1.5$ ft, where the negative sign indicated that she was still moving downward. Finally, we use this in Eq. 2-26 to find the acceleration,

$$(0) = (-96 \text{ ft/s}) + a(0.031 \text{ s}),$$

which gives $a = +3100 \text{ ft/s}^2$. The *important* positive sign is because she is accelerating upward when she stops. In terms of g this is $a = 97g$, which can be found by multiplying through by $1 = g/(32 \text{ ft/s}^2)$.

P2-31 Assume each hand can toss n objects per second. Let τ be the amount of time that any one object is in the air. Then $2n\tau$ is the number of objects that are in the air at any time, where the "2" comes from the fact that (most?) jugglers have two hands. We'll estimate n, but τ can be found from Eq. 2-30 for an object which falls a distance h from rest:

$$0 = h + (0)t - \frac{1}{2}gt^2,$$

solving, $t = \sqrt{2h/g}$. But τ is twice this, because the object had to go up before it could come down. So the number of objects that can be juggled is

$$4n\sqrt{2h/g}$$

We need to estimate n. Do this by standing in front of a bathroom mirror and flapping a hand up and down as fast as you can. I can manage to simulate 10 tosses in 5 seconds while frantic, which means $n = 2$ tosses/second. So the maximum number of objects I could juggle to a height h would be

$$3.6\sqrt{h/\text{meters}}.$$

I doubt I could toss objects higher than 4 meters, so my absolute maximum would be about 7 objects. In reality I almost juggled one object once.

Chapter 3

Force and Newton's Laws

E3-3 We want to find the force on the electron; we do this by first finding the acceleration; that's actually the most involved part of the problem. We are given the distance through which the electron accelerates and the final speed. Assuming constant acceleration we can find the average speed during the interval from Eq. 2-27

$$v_{\mathrm{av},x} = \frac{1}{2}(v_x + v_{0x}) = \frac{1}{2}\Big((5.8\times10^6\ \mathrm{m/s}) + (0)\Big) = 2.9\times10^6\ \mathrm{m/s}.$$

From this we can find the time spent accelerating from Eq. 2-22, since $\Delta x = v_{\mathrm{av},x}\Delta t$. Putting in the numbers, we find that the time is $\Delta t = 5.17\times10^{-9}$s. This can be used in component form of Eq. 2-14 to find the acceleration,

$$a_x = \frac{\Delta v_x}{\Delta t} = \frac{(5.8\times10^6\ \mathrm{m/s}) - (0)}{(5.17\times10^{-9}\mathrm{s})} = 1.1\times10^{15}\mathrm{m/s}^2.$$

We are not done yet. The net force on the electron is from Eq. 3-5,

$$\sum F_x = ma_x = (9.11\times10^{-31}\mathrm{kg})(1.1\times10^{15}\mathrm{m/s}^2) = 1.0\times10^{-15}\ \mathrm{N}.$$

E3-5 The *net* force on the sled is 92 N−90 N= 2 N; we subtract because the forces are in opposite directions. This net force is used with Newton's Second law to find the acceleration; $\sum F_x = ma_x$, so

$$a_x = \frac{\sum F_x}{m} = \frac{(2\,\mathrm{N})}{(25\,\mathrm{kg})} = 8.0\times10^{-2}\mathrm{m/s}^2.$$

E3-9 There are too many unknowns to find a numerical value for the force or for either mass. So don't try. Write the expression for the motions of the first object as $\sum F_x = m_1 a_{1x}$ and that of the second object as $\sum F_x = m_2 a_{2x}$. In both cases there is only one force, F, on the object, so $\sum F_x = F$. We will solve these for the mass as $m_1 = F/a_1$ and $m_2 = F/a_2$. Since $a_1 > a_2$ we can conclude that $m_2 > m_1$

(a) The acceleration of and object with mass $m_2 - m_1$ under the influence of a single force of magnitude F would be

$$a = \frac{F}{m_2 - m_1} = \frac{F}{F/a_2 - F/a_1} = \frac{1}{1/(3.30\,\mathrm{m/s^2}) - 1/(12.0\,\mathrm{m/s^2})},$$

which has a numerical value of $a = 4.55$ m/s^2.

(b) Similarly, the acceleration of an object of mass $m_2 + m_1$ under the influence of a force of magnitude F would be

$$a = \frac{1}{1/a_2 + 1/a_1} = \frac{1}{1/(3.30\,\mathrm{m/s^2}) + 1/(12.0\,\mathrm{m/s^2})},$$

which is the same as part (a) except for the sign change. Then $a = 2.59$ m/s^2.

E3-11 The existence of the spring has little to do with the problem except to "connect" the two blocks; the consequence of this connection is that the force of block 1 on block 2 is equal in magnitude to the force of block 2 on block 1.

(a) The net force on the second block is given by

$$\sum F_x = m_2 a_{2x} = (3.8\,\mathrm{kg})(2.6\,\mathrm{m/s^2}) = 9.9\,\mathrm{N}.$$

There is only one (relevant) force on the block, the force of block 1 on block 2.

(b) There is only one (relevant) force on block 1, the force of block 2 on block 1. By Newton's third law this force has a magnitude of 9.9 N. Then Newton's second law gives $\sum F_x = -9.9$ N$= m_1 a_{1x} = (4.6$ kg$)a_{1x}$. So $a_{1x} = -2.2$ m/s^2 at the instant that $a_{2x} = 2.6$ m/s^2. Note the minus sign, it isn't frivolous; it reflects the fact the two block are necessarily accelerating in opposite directions. We could have instead defined the direction of acceleration of block 2 to be negative, then the acceleration of block 1 would be positive.

E3-15 The numerical weight of an object is given by Eq. 3-7, $W = mg$. If $g = 9.81$ m/s^2, then $m = W/g = (26.0$ N$)/(9.81$ m/s$^2) = 2.65$ kg.

(a) Apply $W = mg$ again, but now $g = 4.60$ m/s^2, so at this point $W = (2.65$ kg$)(4.60$ m/s$^2) = 12.2$ N. Just a reminder; the mass didn't change between these two points, only the *weight* did.

(b) If there is no gravitational force, there is no weight, because $g = 0$. There is still mass, however, and that mass is still 2.65 kg.

E3-19 We'll assume the net force in the x direction on the plane as it accelerates down the runway is from the two engines, so $\sum F_x = 2(1.4\times10^5\text{ N}) = ma_x$. Then $m = 1.22\times10^5$ kg. We want the *weight* of the plane, so

$$W = mg = (1.22\times10^5\text{kg})(9.81\,\text{m/s}^2) = 1.20\times10^6\,\text{N}.$$

E3-23 Look back at Problem 2-25 for a detailed description of solving the first part of this exercise. We won't go through all of the reasoning here.

(a) Find the time during the "jump down" phase from Eq. 2-30. I'll substitute the variables in directly.

$$(0\text{ m}) = (0.48\text{ m}) + (0)t - \frac{1}{2}(9.8\text{ m/s}^2)t^2,$$

which is a simple quadratic with solutions $t = \pm0.31$ s. Only the positive solution is of interest. Use this time in Eq. 2-29 to find his speed when he hit ground,

$$v_y = (0) - (9.8\text{ m/s}^2)(0.31\text{ s}) = -3.1\text{ m/s}.$$

This becomes the initial velocity for the deceleration motion, so his average speed during deceleration is given by Eq. 2-27,

$$v_{\text{av},y} = \frac{1}{2}\left(v_y + v_{0y}\right) = \frac{1}{2}\left((0) + (-3.1\text{ m/s})\right) = -1.6\text{ m/s}.$$

This average speed, used with the distance of -2.2 cm (-0.022 m), can be used to find the time of deceleration

$$v_{\text{av},y} = \Delta y/\Delta t,$$

and putting numbers into the expression gives $\Delta t = 0.014$ s. Finally, we use this in Eq. 2-26 to find the acceleration,

$$(0) = (-3.1\text{ m/s}) + a(0.014\text{ s}),$$

which gives $a = 220\text{ m/s}^2$.

(b) The average *net* force on the man is

$$\sum F_y = ma_y = (83\,\text{kg})(220\,\text{m/s}^2) = 1.8\times10^4\text{N}.$$

This *isn't* the force of the ground on the man, and it isn't the force of gravity on the man; it is the *vector sum* of these two forces. That the net force is positive means that it is directed up; a direct consequence is that the *upward* force from the ground must have a larger magnitude than the *downward* force of gravity.

E3-25 Remember that pounds are a measure of force, not a measure of mass. From appendix G we find 1 lb = 4.448 N; so the weight is (100 lb)(4.448 N/1 lb) = 445 N; similarly the cord will break if it pulls upward on the object with a force greater than 387 N. It will be necessary to know the mass of the object sooner or later, using Eq. 3-7, $m = W/g = (445\text{ N})/(9.8\text{ m/s}^2) = 45$ kg.

There are two vertical forces on the 45 kg object, an upward force from the cord F_{OC} (which has a maximum value of 387 N) and a downward force from gravity F_{OG}. Since the objective is to *gently* lower the object we will assume the upward force is as large as it can be. Then $\sum F_y = F_{OC} - F_{OG} = (387\text{ N}) - (445\text{ N}) = -58$ N. Since the net force is negative, the object must be accelerating downward according to

$$a_y = \sum F_y/m = (-58\,\text{N})/(45\,\text{kg}) = -1.3\,\text{m/s}^2.$$

So long as you lower the cord with this acceleration (or greater), the upward force on the object from the cable will be *less* than the breaking strength. But don't stop! The instant that you feed the cord out with an acceleration of less than -1.3 m/s^2 the cord will snap, and the object will fall with an acceleration equal to g.

E3-31 (a) The vertical (upward) force from the air on the blades, F_{BA}, can be considered to act on a system consisting of the helicopter alone, or the helicopter + car (or is it a Hummer?). We choose the latter; the *total* mass of this system is 19,500 kg; and the only other force acting on the system is the force of gravity, which is

$$W = mg = (19,500\,\text{kg})(9.8\,\text{m/s}^2) = 1.91\times 10^5\,\text{N}.$$

The force of gravity is directed down, so the net force on the system is $\sum F_y = F_{BA} - (1.91\times 10^5\text{ N})$. The net force can also be found from Newton's second law: $\sum F_y = ma_y = (19,500\text{ kg})(1.4\text{ m/s}^2) = 2.7\times 10^4$ N. The positive sign for the acceleration was important; the object was accelerating *up*. Equate the two expression for the net force, $F_{BA} - (1.91\times 10^5\text{ N}) = 2.7\times 10^4$ N, and solve; $F_{BA} = 2.2\times 10^5$ N.

(b) We basically repeat the above steps except: (1) the system will consist only of the car, and (2) the upward force on the car comes from the supporting cable only F_{CC}. Then the weight of the car is $W = mg = (4500\text{ kg})(9.8\text{ m/s}^2) = 4.4\times 10^4$ N. The net force is $\sum F_y = F_{CC} - (4.4\times 10^4\text{ N})$, it can also be written as $\sum F_y = ma_y = (4500\text{ kg})(1.4\text{ m/s}^2) = 6300$ N. Equating, $F_{CC} = 50,000$ N.

P3-3 (a) Start with block one. It starts from rest, accelerating through a distance of 16 m in a time of 4.2 s. Applying Eq. 2-28,

$$\begin{aligned} x &= x_0 + v_{0x}t + \frac{1}{2}a_x t^2, \\ -16\text{ m} &= (0) + (0)(4.2\text{ s}) + \frac{1}{2}a_x(4.2\text{ s})^2 \end{aligned}$$

we find the acceleration to be $a_x = -1.8$ m/s^2. The negative sign is because I choose the convention that lower down the ramp is negative.

Now for the second block. The acceleration of the second block is identical to the first for much the same reason that all objects fall with approximately the same acceleration. See the statement at the end of the problem.

(b) The second block is projected up the plane with some initial velocity, rises to some highest point, and then slides back down. Since the acceleration while the block moves up the plane is the same as the acceleration while the block moves down the plane, it is reasonable to assume that the motion is symmetric: the magnitude of the initial velocity at the bottom of the incline is the same as the magnitude of the final velocity on the way down; the time it takes to go up the ramp is the same as the time it takes to come back down.

If the initial and final velocities are related by a sign, then $v_x = -v_{0x}$ and Eq. 2-26 would become

$$\begin{aligned} v_x &= v_{0x} + a_x t, \\ -v_{0x} &= v_{0x} + a_x t, \\ -2v_{0x} &= (-1.8 \text{ m/s}^2)(4.2 \text{ s}). \end{aligned}$$

which gives an initial velocity of $v_{0x} = 3.8$ m/s.

(c) The time it takes the second block to go up the ramp is the same as the time it takes to come back down. This means that half of the time is spent coming down from the highest point, so the time to "fall" is 2.1 s. The distance traveled is found from Eq. 2-28,

$$x = (0) + (0)(2.1\,\text{s}) + \frac{1}{2}(-1.8\,\text{m/s}^2)(2.1\,\text{s})^2 = -4.0\,\text{m}.$$

The negative sign is because it ended up *beneath* the starting point.

P3-7 This problem requires repeated, but careful, application of Newton's second law.

(a) Consider all three carts as one system. There is one (relevant) force $P = 6.5$ N on this system. Then $\sum F_x = P = 6.5$ N. It is the total mass of the system that matters, so Newton's second law will be applied as

$$\begin{aligned} \sum F_x &= m_{\text{total}} a_x, \\ 6.5 \text{ N} &= (3.1\,\text{kg} + 2.4\,\text{kg} + 1.2\,\text{kg}) a_x, \\ 0.97 \text{ m/s}^2 &= a_x. \end{aligned}$$

(b) Now choose your system so that it only contains the third car. There is one force on the third car, the pull from car two F_{23} directed to the right, so $\sum F_x = F_{23}$ if we choose the convention that right is positive. We know the acceleration of the car from part (a), so our application of Newton's second law will be

$$\sum F_x = F_{23} = m_3 a_x = (1.2\,\text{kg})(0.97\,\text{m/s}^2).$$

The unknown can be solved to give $F_{23} = 1.2\,\text{N}$ directed to the right.

(c) We can either repeat part (b) except apply it to the second and third cart combined, or we can just look at the second cart. Since looking at the second and third cart combined involves fewer forces, we'll do it that way. There is one (relevant) force on our system, F_{12}, the force of the first cart on the second. The $\sum F_x = F_{12}$, so Newton's law applied to the system gives

$$F_{12} = (m_2 + m_3)a_x = (2.4\,\text{kg} + 1.2\,\text{kg})(0.97\,\text{m/s}^2) = 3.5\,\text{N}.$$

The system contained two masses, so we need to add them in the above expression.

P3-11 This problem is really no different than Problem 3-7, except that there are no numbers here. The horizontal force $\vec{\mathbf{P}}$ is a vector of magnitude P, and since the only relevant quantities in this problem are directed along what I'll conveniently choose to call the x-axis, we'll restrict ourselves to a scalar presentation.

(a) Treat the system as including both the block and the rope, so that the mass of the system is $M + m$. There is one (relevant) force which acts on the system, so $\sum F_x = P$. Then Newton's second law would be written as $P = (M + m)a_x$. Solve this for a_x and get $a_x = P/(M + m)$.

(b) Now consider only the block. The horizontal force doesn't act on the block; instead, there is the force of the rope on the block. We'll assume that force has a magnitude R, and this is the *only* (relevant) force on the block, so $\sum F_x = R$ for the net force on the block.. In this case Newton's second law would be written $R = Ma_x$. Yes, a_x is the same in part (a) and (b); the acceleration of the block is the same as the acceleration of the block + rope. Substituting in the results from part (a) we find

$$R = \frac{M}{M + m}P.$$