99 *Record accelerations.* When Kitty O'Neil set the dragster records for the greatest speed and least elapsed time by reaching 392.54 mi/h in 3.72 s, what was her average acceleration in (a) meters per second squared and (b) g units? When Eli Beeding, Jr., reached 72.5 mi/h in 0.0400 s on a rocket sled, what was his average acceleration in (c) meters per second squared and (d) g units? For each person, assume the motion is in the positive direction of an x axis.

Appendix D : $1 \ mi/h = 0.4470 \ m/s$

$v_0 = 0$

$v = 392.54 \ mi/h = 392.54 \times 0.4470 = 175.46 \ m/s$

$\Delta t = 3.72 \ s$

a) $\bar{a} = \dfrac{\Delta v}{\Delta t} = \dfrac{175.46}{3.72} \simeq 47.168 \simeq 47.2 \ m/s^2$

b) $\bar{a} = 47.168 \div 9.8 \simeq 4.81 g$

$v_0 = 0$

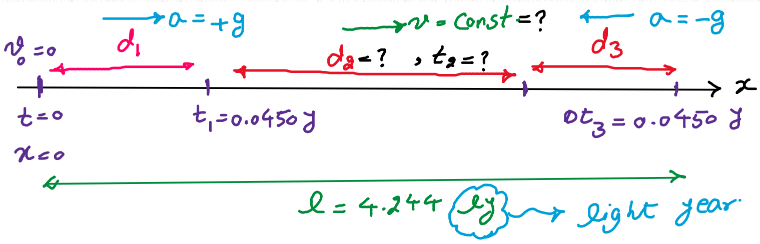
$v = 72.5 \ mi/h = 72.5 \times 0.4470 \simeq 32.407 \ m/s$

$\Delta t = 0.0400 \ s$

c) $\bar{a} = \dfrac{\Delta v}{\Delta t} = \dfrac{32.407}{0.0400} \simeq 810.188 \simeq 810 \ m/s^2$

d) $\bar{a} = 810.188 \div 9.8 \simeq 82.7 g$

100 *Travel to a star.* How much time would be required for a starship to reach Proxima Centauri, the star closest to the Sun, at a distance of $L = 4.244$ light years (ly)? Assume that it starts from rest, maintains a comfortable acceleration magnitude of $1.000g$ for the first 0.0450 y and a deceleration (slowing) magnitude of $1.000g$ for the last 0.0450 y, and cruises at constant speed in between those periods.



acceleration phase : $v = at + v_0 = 9.76 \times 10^{15} \times 0.0450 \simeq 4.39 \times 10^{14} \ m/year$

$v_0 = 0$

$a = 9.8 \ m/s^2$, $1 \ year = 365.25 \times 24 \times 3600 = 31'557'600 \ s \longrightarrow 1 \ s = \dfrac{1}{31'557'600} \ year$

$a = 9.8 \times \dfrac{m}{\left(\dfrac{1}{31'557'600} \ year\right)^2} \simeq 9.76 \times 10^{15} \ m/(year)^2$

d_1

$x = \frac{1}{2}at^2 + v_0 t + x_0 \longrightarrow d_1 = \frac{1}{2} \times 9.76 \times 10^{15} \times (0.0450)^2 \simeq 9.89 \times 10^{12} \ m = d_3$

$v_0 = 0$, $x_0 = 0$

$x = vt = 3 \times 10^8 \times 31'557'600 \simeq 9.467 \times 10^{15} \ m$

$\ell = 4.244 \times 9.467 \times 10^{15} \simeq 4.018 \times 10^{16} \ m \longrightarrow d_2 = \ell - (d_1 + d_3) \simeq \ell$

$v = \text{const. phase} \longrightarrow d_2 = v . t_2 \longrightarrow t_2 = \dfrac{4.018 \times 10^{16}}{4.39 \times 10^{14}} \ 10^2 \simeq 91.526 \ year$

$\longrightarrow T = t_1 + t_2 + t_3 = 91.526 + 2 \times 0.0450 \simeq 91.63 \ year$

101 CALC *Bobsled acceleration.* In the start of a four-person bobsled race, two drivers (a pilot and a brakeman) are already on board while two pushers accelerate the sled along the ice by pushing against the ice with spiked shoes. After pushing for 50 m along a straight course, the pushers jump on board. The acceleration during the pushing largely determines the time to slide through the rest of the course and thus decides the winner with the least run time, which often depends on differences of 1.0 ms. Consider an x axis along the 50 m, with the origin at the start position. If the position x versus time t in the pushing phase is given by $x = 0.3305t^2 + 4.2060t$ (in meters and seconds), then at the end of a 9.000 s push what are (a) the speed and (b) the acceleration?

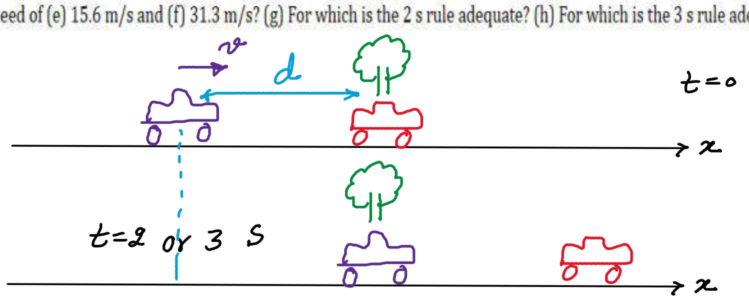
$x = 0.3305t^2 + 4.2060t$; $x : m$, $t : s$

a) $v = \frac{dx}{dt} = 0.3305 \times 2t + 4.2060 = 0.661t + 4.2060$

$v(t=9) = 0.661 \times 9 + 4.2060 \simeq 10.155 \simeq 10.16 \ m/s$

b) $a = \frac{dv}{dt} = \frac{d^2x}{dt^2} = \frac{d}{dt}(0.661t + 4.2060) = 0.661 \Rightarrow a \simeq 0.6610 \ m/s^2$

102 *Car-following stopping distance.* When you drive behind another car, what is the minimum distance you should keep between the cars to avoid a rear-end collision if the other car were to suddenly stop (it hits, say, a stationary truck)? Some drivers use a "2 second rule" while others use a "3 second rule." To apply such rules, pick out an object such as a tree alongside the road. When the front car passes it, begin to count off seconds. For the first rule, you want to pass that object at a count of 2 s, and for the second rule, 3 s. For the 2 s rule, what is the resulting car–car separation at a speed of (a) 15.6 m/s (35 mi/h, slow) and (b) 31.3 m/s (70 mi/h, fast)? For the 3 s rule, what is the car–car separation at a speed of (c) 15.6 m/s and (d) 31.3 m/s? To check if the results give safe trailing distances, find the stopping distance required of you at those initial speeds. Assume that your car's braking acceleration is -8.50 m/s^2 and your reaction time to apply the brake upon seeing the danger is 0.750 s. What is your stopping distance at a speed of (e) 15.6 m/s and (f) 31.3 m/s? (g) For which is the 2 s rule adequate? (h) For which is the 3 s rule adequate?

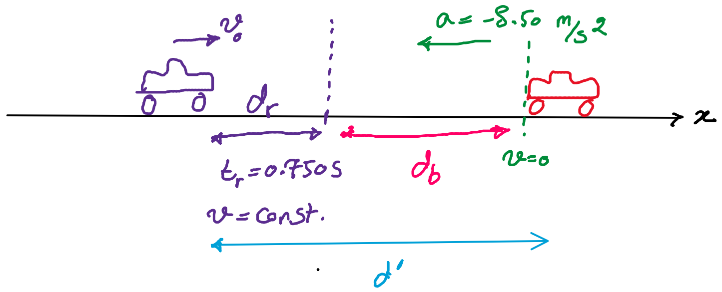


a) $v = 15.6 \ m/s$, $t = 2 \Rightarrow d = v.t = 15.6 \times 2 = 31.2 \ m$

b) $v = 31.3 \ m/s$, $t = 2 \Rightarrow d = v.t = 31.3 \times 2 = 62.6 \ m$

c) $v = 15.6 \ m/s$, $t = 3 \Rightarrow d = v.t = 15.6 \times 3 = 46.8 \ m$

d) $v = 31.3 \ m/s$, $t = 3 \Rightarrow d = v.t = 31.3 \times 3 = 93.9 \ m$



e) $v_0 = 15.6 \ m/s$

$d_r = v_0 t_r = 15.6 \times 0.750 = 11.7 \ m$

$\cancel{v^2}^{0} - v_0^2 = 2a d_b \Rightarrow -(15.6)^2 = 2 \times (-8.50) \times d_b \Rightarrow d_b = \frac{(15.6)^2}{2 \times 8.50} = 14.32 \ m$

$\Rightarrow d = d_b + d_r = 11.7 + 14.32 \simeq 26.02 \simeq 26.0 \ m$ → both rules are adequate

f) $v_0 = 31.3 \ m/s$

$d_r = v_0 \cdot t_r = 31.3 \times 0.750 = 23.475 \ m$

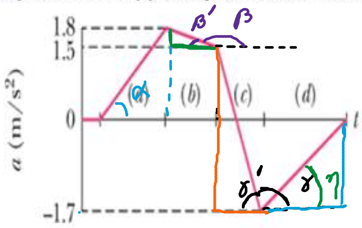
$v_f^2 - v_0^2 = 2ad_b \longrightarrow -(31.3)^2 = 2 \times (-8.50) \times d_b \Rightarrow d_b = \frac{(31.3)^2}{2 \times 8.50} \simeq 57.63 \ m$

$v_f = 0$

$\Rightarrow d = 23.475 + 57.63 \simeq 81.10 \simeq 81.1 \ m$ → only rule 3 is adequate

103 *Vehicle jerk indicating aggression.* One common form of aggressive driving is for a trailing driver to repeat a pattern of accelerating suddenly to come close to the car in front and then braking suddenly to avoid a collision. One way to monitor such behavior, either remotely or with an onboard computer system, is to measure *vehicle jerk*, where jerk is the physics term for the time rate of change of an object's acceleration along a straight path. Figure 2.38 is a graph of acceleration *a* versus time *t* in a typical situation for a car. Determine the jerk for each of the time periods: (a) gas pedal pushed down rapidly, 2.0 s interval, (b) gas pedal released, 1.5 s interval, (c) brake pedal pushed down rapidly, 1.5 s interval, (d) brake pedal released, 2.5 s interval.

$\text{jerk} = \frac{da}{dt}$, $da \to m/s^2$, $dt \to s$, jerk $\to m/s^3$



$a = \frac{dv}{dt}$

$v = \frac{dx}{dt}$

a) $\text{jerk} = \tan\alpha = \frac{1.8}{2.0} = 0.90 \ m/s^3$

b) $\text{jerk} = \tan\beta = \tan(\pi - \beta') = -\tan\beta' = -\frac{1.8 - 1.5}{1.5} = -0.20 \ m/s^3$

c) $\text{jerk} = \tan\gamma = \tan(\pi - \gamma') = -\tan\gamma' = -\frac{1.5 + 1.7}{1.5} \simeq -2.1 \ m/s^3$

d) $\text{jerk} = \tan\eta = \frac{1.7}{2.5} = 0.68 \ m/s^3$

104 *Metal baseball bat danger.* Wood bats are required in professional baseball but metal bats are sometimes allowed in youth and college baseball. One result is that the *exit speed v* of the baseball off a metal bat can be greater. In one set of measurements under the same circumstances, *v* = 50.98 m/s off a wood bat and *v* = 61.50 m/s off a metal bat. Consider a ball hit directly toward the pitcher. The regulation distance between pitcher and batter is Δ*x* = 60 ft 6 in. For those measured speeds, how much time Δ*t* does the ball take to reach the pitcher for (a) the wood bat and (b) the metal bat? (c) By what percentage would Δ*t* be reduced if professional baseball switched to metal bats? Because pitchers do not wear any protective equipment on face or body, the situation is already dangerous and the switch would add to that danger.

Appendix D: 1 ft = 0.3048 m

$1 \text{ in} = 2.540 \times 10^{-2} \ m$

wood bat : $v_1 = 50.98 \ m/s$

metal bat : $v_2 = 61.5 \ m/s$

$\Delta x = 60 \text{ ft}, 6 \text{ in} = 60 \times 0.3048 + 6 \times 2.540 \times 10^{-2} = 18.44 \ m$

a) $\Delta x = v_1 \cdot \Delta t_1 \Rightarrow \Delta t_1 = \frac{\Delta x}{v_1} = \frac{18.44}{50.98} \simeq 0.3617 \ s$

b) $\Delta x = v_2 \cdot \Delta t_2 \Rightarrow \Delta t_2 = \frac{\Delta x}{v_2} = \frac{18.44}{61.5} \simeq 0.2998 \ s$

c) $\text{Percentage} = \frac{\Delta t_2 - \Delta t_1}{\Delta t_1} \times 100 = \frac{0.2998 - 0.3617}{0.3617} \times 100 \simeq -17.11\%$