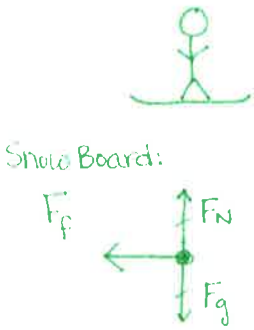
Essential Practice with Newton's 2nd Law ANSWER KEY

***Instructions**: Answer the following questions in your journal. Make sure to draw a FBD for each situation and show all of your work completely. Please indicate net force next to your FBD.*

1. A 3.0 kg snowboard is freely sliding on level snow. It slows down at a rate of -0.15 $^{m}/_{s^2}$. What is the **friction force** between the board and the snow? What is μ?



$m = 3\text{kg}$

$a = -0.15\ ^{m}/_{s^2}$

$F_f = ?$

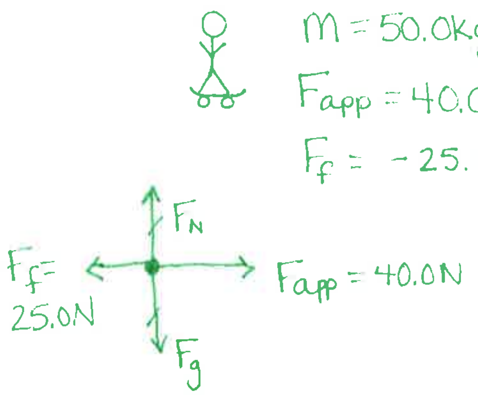
$F_{NET} = F_f = ma$

$F_f = ma = (3.0\text{kg})(-0.15\ ^{m}/_{s^2})$

$\boxed{F_f = -0.45\text{ N}} \Rightarrow F_f = \mu \cdot F_N \leftarrow$ Eq. to F_g

$\mu = \frac{F_f}{m \cdot g} = \frac{-0.45\text{N}}{(3.0\text{kg})(-9.80\ ^{m}/_{s^2})}$ $\boxed{\mu = 0.015}$

2. You and your skateboard have a combined mass of 50.0 kg. Your friend pushes you with a force of 40.0 N against 25.0 N of friction. What is your resulting **acceleration**?



$m = 50.0\text{kg}$

$F_{app} = 40.0\text{N}$

$F_f = -25.0\text{ N}$

$F_{NET} = ma$

$F_{NET} = F_{app} + F_f$

$ma = F_{app} + F_f$

$a = \frac{F_{app} + F_f}{m} = \frac{40.0\text{N} - 25.0\text{N}}{50.0\text{kg}}$

$\boxed{a = 0.3\ ^{m}/_{s^2}}$

3. A 5$\bar{0}$,000 kg Titan IV rocket fires for 60. seconds. The thrust of the engines provides a <u>**net**</u> **upward force** of 2$\bar{0}$0,000 N.
   a. What is the total upward thrust of the rockets?
   b. What is the resulting acceleration of the rocket?
   c. What is the speed of the rocket at the end of 60. seconds?

a. $F_{NET} = F_{Thrust} - F_g \Rightarrow F_{Thrust} = F_{NET} + F_g \rightarrow F_g = m \cdot g$

$F_{Thrust} = 2\bar{0}0{,}000\text{N} + (5\bar{0}{,}000\text{ kg})(9.80\ ^{m}/_{s^2})$

$\boxed{F_{Thrust} = 690{,}000\text{N}}$

b. $F_{NET} = ma \Rightarrow a = \frac{F_{NET}}{m} = \frac{2\bar{0}0{,}000\text{N}}{5\bar{0}{,}000\text{kg}}$

$\boxed{a = 4.0\ ^{m}/_{s^2}}$

c. $V_2 = \cancel{V_1}^{\,0} + at$

$V_2 = (4.0\ ^{m}/_{s^2})(60.\text{ s})$

$\boxed{V_2 = 240\ ^{m}/_{s}}$

4. Pierce, mass of 60.0 kg, is riding his bike at 20.0 $^{m}/_{s}$. He hits a rock and flies through the air (his inertia still carries him through the air with a horizontal velocity of 20.0 $^{m}/_{s}$ after he is knocked off his bike). Then he smacks into a tree.
   a. If the time over which the tree impact lasts is 0.200 seconds, what is the **force** exerted by the tree on Pierce?

$m = 60.0\,kg$

$V_1 = 20.0\,m/s$

$V_2 = 0$ (he stops!)

$t = 0.200\,s$

$a = ?$

$a = \frac{\cancel{V_2}^{0} - V_1}{t} = \frac{-20.0\,m/s}{0.200\,s}$

$a = 100.\,m/s^2$

$F_{NET} = ma = (60.0\,kg)(100.\,m/s^2)$

$\boxed{F_{NET} = 6\bar{0}\bar{0}0\,N}$

5. Troy is riding an elevator. On this day, Troy's mass is 75 kg. He is standing on a bathroom scale that reads weight in Newtons. **What does the scale read when:** *(What this question is really asking is, "How hard does the scale have to push up in order to cause the resulting motion?" The scale is really measuring the force that the elevator is applying to Pat)*
   a. Troy is at rest:
   b. Troy is accelerating up at 3 $^{m}/_{s^2}$
   c. Troy is moving at a constant rate of 8 $^{m}/_{s}$
   d. Troy is accelerating down at 2 $^{m}/_{s^2}$

$m = 75\,kg$

a. At rest, $F_N = F_g = mg$

$F_N = (75\,kg)(9.80\,m/s^2)$

$\boxed{F_N = 735\,N}$

b. F_{NET} is ↑ so $F_N > F_g$ (use equations from blue sheet)

$F_{NET} = F_N - F_g \Rightarrow ma = F_N - mg$

$F_N = m(a+g) = (75\,kg)(3\,m/s^2 + 9.80\,m/s^2)$

$\boxed{F_N = 960\,N}$

c. $F_{NET} = 0 \Rightarrow F_N = F_g$ $\boxed{F_N = 735\,N}$

d. F_{NET} is ↓ so $F_N < F_g$

$-F_{NET} = F_N - F_g \Rightarrow -ma = F_N - mg$

$F_N = m(g-a) = (75\,kg)(9.80\,m/s^2 - 2\,m/s^2)$

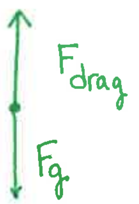
$\boxed{F_N = 585\,N}$

6. Abed is skydiving!! Initially, Abed's (m = 75 kg) acceleration is 9.80 $^{m}/_{s^2}$. Then after a few seconds, it reduces to 8.00 $^{m}/_{s^2}$.
   a. What is the **force of air drag** at the moment when Abed's acceleration is 8.00 $^{m}/_{s^2}$?
   b. After 10.0 seconds, Abed's acceleration decreases to only 4.00 $^{m}/_{s^2}$. What is the **force of air drag** now? Is Abed still gaining speed as he falls?
   c. Abed reaches a point where his acceleration equals 0 $^{m}/_{s^2}$! **Describe** what his motion is like now. What is the **force of air drag**?
   d. Abed opens his parachute. He slows down initially at a rate of -5.00 $^{m}/_{s^2}$ (he's losing 5.00 $^{m}/_{s}$in speed every second). What is the **force of air drag** now?

(Down is + direction)

$m = 75\,kg$

$a = 8.00\,m/s^2$



a. $F_{NET} = ma = -F_{drag} + F_g$

$F_{drag} = mg - ma = m(g-a)$

$F_{drag} = (75\,kg)(9.80\,m/s^2 - 8.00\,m/s^2)$

$\boxed{F_{drag} = -135\,N}$ ← upward!

b. $F_{drag} = m(g-a) = (75\,kg)(9.80\,m/s^2 - 4.00\,m/s^2)$

$\boxed{F_{drag} = -435\,N}$ upward!

Yes, Abed is still accelerating so he still gains speed.

c. $F_{drag} = F_g = mg \; (F_{NET} = 0)$

$= (75\,kg)(9.80\,m/s^2)$

$\boxed{F_{drag} = -735\,N}$ upward!

Abed is falling at a constant speed $(a = 0!)$

d. $-F_{NET} = -F_{drag} + F_g$

$F_{drag} = ma + mg = m(a+g)$

$= (75\,kg)(9.80\,m/s^2 + 5.00\,m/s^2)$

$\boxed{F_{drag} = -1110\,N}$ → upward!

7. Car safety has improved dramatically over the last two decades. **Crumple zones** allow the front of the car to "squish up" during a crash, protecting the occupants from serious injury. Consider the following two cases.
   a. Jeff drives his 1972 Lincoln Town car (steel frame front end and bumper, mass = 652kg) into a brick wall. The car's initial velocity is 25 $^{m}/_{s}$, and it bounces away from the wall after the collision at a velocity of -3.0 $^{m}/_{s}$. The car was in contact with the wall for 0.12 seconds. Show your process (equations in variable form) including proper units to calculate the **average net force** acting on the car during the collision.
   b. Annie drives her Subaru Outback (front end crumple zone, m = 534 kg) into a brick wall. The car's initial velocity is 25 $^{m}/_{s}$, but this time, instead of bouncing off the wall, the car "squishes" to a stop. The car crumpled up a total distance of 2.25m. Again, show your process (may be different from that above) for calculating the **average net force** acting on the car during the collision.
   c. By what percent is the impact force reduced with a crumple zone? What is the significance of the crumple zone in car safety? Describe all the physics involved that made Jeff's impact force so much larger than the Annie's.

a. $m_L = 652\,kg$

$V_{1L} = 25\,m/s$

$V_{2L} = -3.0\,m/s$

$t_L = 0.12\,s$

$a_L = ?$

$F_{NET(L)} = ?$

$$a_L = \frac{V_{2L} - V_{1L}}{t_L} = \frac{-3.0\,m/s - 25\,m/s}{0.12\,s}$$

$$\underline{a_L = -233\,m/s^2}$$

$$F_{NET(L)} = m_L a_L = (652\,kg)(-233\,m/s^2)$$

$$\boxed{F_{NET(L)} = 152{,}133\,N} = 150{,}000\,N \text{ (2 s.f.)}$$

b. $m_S = 534\,kg$

$V_{1S} = 25\,m/s$

$V_{2S} = 0\,m/s$

$d_S = 2.25\,m$

$a_S = ?$

$F_{NET(S)} = ?$

$$V_2^2 = V_1^2 + 2ad \Rightarrow a = \frac{V_2^2 - V_1^2}{2d}$$

$$a_S = \frac{(0)^2 - (25\,m/s)^2}{2(2.25\,m)}$$

$$\underline{a_S = -139\,m/s^2}$$

$$F_{NET} = ma = (534\,kg)(-139\,m/s^2)$$

$$\boxed{F_{NET(S)} = 74{,}167\,N} = 74{,}000\,N \text{ (2 s.f.)}$$

c. Reduced → 152,133 − 74,167 = $\underline{77{,}966\,N}$

$$\frac{77{,}966\,N}{152{,}133\,N} = \boxed{51\%!}$$

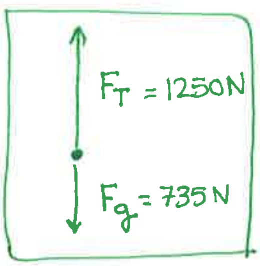
Larger mass, bounced back, larger decelleration

8. Britta bungee jumps for the first time! She jumps fearlessly! The tension in the bungee cord starts at zero and increases all the way to the bottom of her fall.
   a. At any time on the way down is the **net force** on Britta zero? **Explain.**
   b. **Describe** the point in the jump where Britta's downward velocity is greatest.
   c. At the bottom of the jump, the tension in the bungee cord is 1.7 times greater than Britta's weight. If Britta's mass is 75 kg:
      - ☑ Draw a **quantitative FBD** of Britta at the bottom of the jump.
      - ☑ Calculate the **net force** on Britta at the bottom of the jump.
      - ☑ Calculate Britta's **acceleration** at the bottom of the jump.
      - ☑ What is Britta's **instantaneous velocity** at the bottom of the jump?
      - ☑ Is it possible for an object to have zero velocity and non-zero acceleration at the same time? **Explain.**

a. Yes! When the Force of tension equals Britta's weight, net force is 0 N! This happens when she stops bouncing and comes to rest.

b. Just before Britta slows to a stop, $F_T < F_g$. This means she is accellerating downward (direction of net force), so Britta speeds up to her maximum speed. At the point when $F_T = F_g$ she is at her maximum velocity!

c.



$F_g = mg = (75\,kg)(9.80\,m/s^2) = 735N$

$F_T = 1.7\,F_g = 1.7\,(735\,N) = 1250N$

$F_{NET} = F_T - F_g = 1250\,N - 735N$

$\boxed{F_{NET} = 515\,N}$ upward!

$F_{NET} = ma \Rightarrow a = \frac{F_{NET}}{m} = \frac{515\,N}{75\,kg}$

$\boxed{a = 6.9\,m/s^2}$ upward!

$\boxed{V_{@bottom} = 0\,m/s}$ She has to change direction!

$\boxed{\text{Yes!}}$ This occurs at the bottom of the jump!

9. What is the gravitational force between the Earth and the Moon? The Earth has a mass of 5.97×10^{24} kg; the Moon has a mass of 7.35×10^{22} kg; the Moon is on average 3.84×10^{8} m from the Earth.

$$F_G = \frac{G m_1 m_2}{r^2}$$

$$= \frac{(6.67 \times 10^{-11} \frac{m^3}{kg s^2})(5.97 \times 10^{24} kg)(7.35 \times 10^{22} kg)}{(3.84 \times 10^{8} m)^2}$$

$$\boxed{F_G = 1.97 \times 10^{20} N}$$