

At the end of this worksheet you should be able to

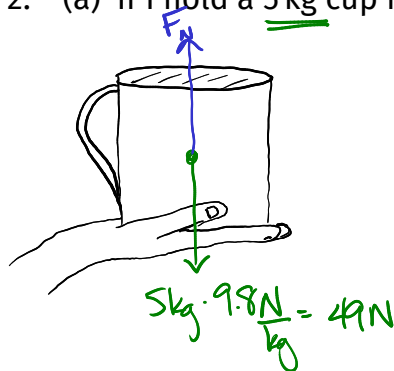
- discuss Newton's laws and provide examples of the application of each.
- apply Newton's first law to solve interesting physical problems.
- apply Newton's second law to solve interesting physical problems for objects that accelerate.
- apply Newton's third law to situations involving the motion of multiple objects.

1. What base units are the composite force units of Newtons equal to?

$$\Sigma F = m \cdot a$$

$$[\text{Newtons}] = [\text{kg}] \left[ \frac{\text{m}}{\text{s}^2} \right]$$

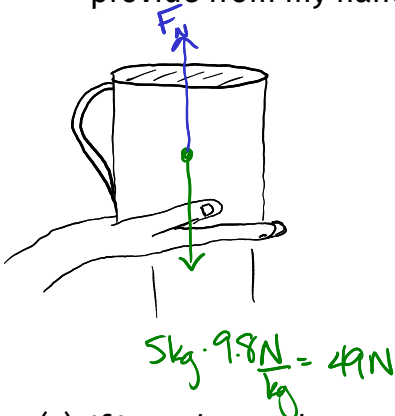
2. (a) If I hold a 5 kg cup motionless in my hand, what force do I provide to the cup?



	x	y
$F_G$	0	-49 N
$F_N$	0	$F_N$
	0	0

$$F_N = 49 \text{ N}$$

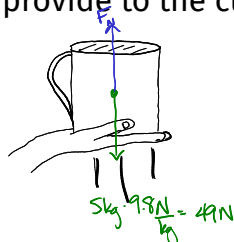
(b) If I raise a 5 kg cup with my hand, at constant speed, then what force do I need to provide from my hand to the cup?



	x	y
$F_G$	0	-49 N
$F_N$	0	$F_N$
	0	0

$$F_N = 49 \text{ N}$$

(c) If I accelerate the cup upwards with an acceleration of  $+1 \text{ m/s}^2$ , then what force does my hand need to provide to the cup?

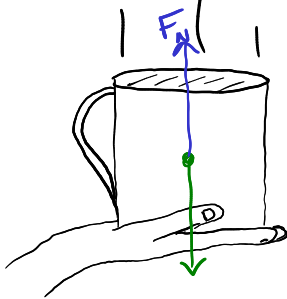


$$\begin{aligned} \Sigma F_y &= ma_y \\ &= 5 \text{ kg} \cdot (+1 \frac{\text{m}}{\text{s}^2}) \\ \Sigma F_y &= 5 \text{ N} \end{aligned}$$

	x	y
$F_G$	0	-49 N
$F_N$	0	$F_N$
	0	5 N

$$\begin{aligned} -49 \text{ N} + F_N &= 5 \text{ N} \\ F_N &= 54 \text{ N} \end{aligned}$$

- (d) If I accelerate the cup downwards with an acceleration of  $-1 \text{ m/s}^2$ , then what force does my hand need to provide to the cup?



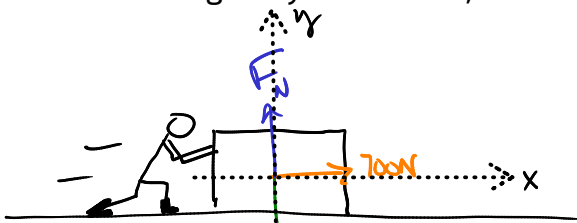
$$\begin{aligned}\Sigma F_y &= ma_y \\ &= 5 \text{ kg} \cdot (-1 \text{ m/s}^2) \\ \Sigma F_y &= -5 \text{ N}\end{aligned}$$

	x	y
$F_G$	0	-49 N
$F_N$	0	$F_N$
	0	-5 N

$$\begin{aligned}-49 \text{ N} + F_N &= -5 \text{ N} \\ F_N &= \underline{\underline{44 \text{ N}}}\end{aligned}$$

$$5 \text{ kg} \cdot 9.8 \frac{\text{N}}{\text{kg}} = 49 \text{ N}$$

3. If I push a 100 kg box with an applied force of 700 N along a friction-less surface. Find the force of gravity on the box, the normal force, and the net force.



$$\begin{aligned}F_G &= 100 \text{ kg} \cdot 9.8 \frac{\text{N}}{\text{kg}} \\ F_G &= 980 \text{ N}\end{aligned}$$

	x	y
$F_G$	0	-980
$F_N$	0	$F_N$
$F_A + 700 \text{ N}$	0	0

$$-980 + F_N = 0$$

$$F_N = \underline{\underline{980 \text{ N}}}$$

$$\Sigma F = +700 \text{ N} \quad | \quad 0$$

vector  
addition

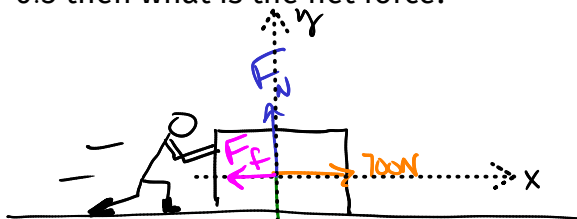
Newton's 2nd  
 $a_y = 0 \therefore \Sigma F_y = 0$

Bonus: what is the acceleration?

$$\Sigma F_x = ma_x$$

$$700 \text{ N} = 100 \text{ kg} \cdot a_x \Rightarrow a_x = 7 \text{ m/s}^2$$

4. Take the same problem from above and now add friction. The coefficient of friction is  $\mu = 0.5$  then what is the net force?



$$\begin{aligned}F_G &= 100 \text{ kg} \cdot 9.8 \frac{\text{N}}{\text{kg}} \\ F_G &= 980 \text{ N}\end{aligned}$$

	x	y
$F_G$	0	-980 N
$F_N$	0	$F_N \rightarrow +980 \text{ N}$
$F_A + 700 \text{ N}$	0	0
$F_f$	-490 N	0
	$\Sigma F = +210 \text{ N}$	0

What is the acceleration now?

$$210 \text{ N} = 100 \text{ kg} \cdot a_x \Rightarrow a_x = 2.1 \text{ m/s}^2 \quad \checkmark$$

5. For both of the previous problem, what happens when I stop pushing?

frictionless #3

$$a_x \Rightarrow 0 \text{ m/s}^2$$

frictionfull #4

	x	y
$F_g$	0	-980N
$F_w$	0	$F_w \rightarrow$
$F_a$	0	0
$F_f$	-490N	0
$\Sigma F$	-490N	0

$$\Sigma F_x = m a_x$$

$$-490 \text{ N} = 100 \text{ kg} \cdot a_x$$

$$a_x = -4.9 \frac{\text{m}}{\text{s}^2}$$

6. What force do I need to exert to push the box at constant speed?

frictionless #3

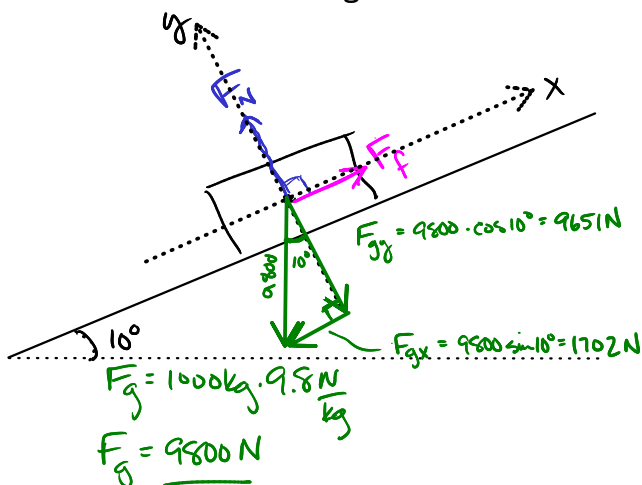
$$F_A = 0 \text{ N}$$

frictionfull #4

	x	y
$F_g$	0	-980N
$F_w$	0	$F_w \rightarrow$
$F_a + 490 \text{ N}$	0	0
$F_f$	-490N	0
$\Sigma F$	0 N	0

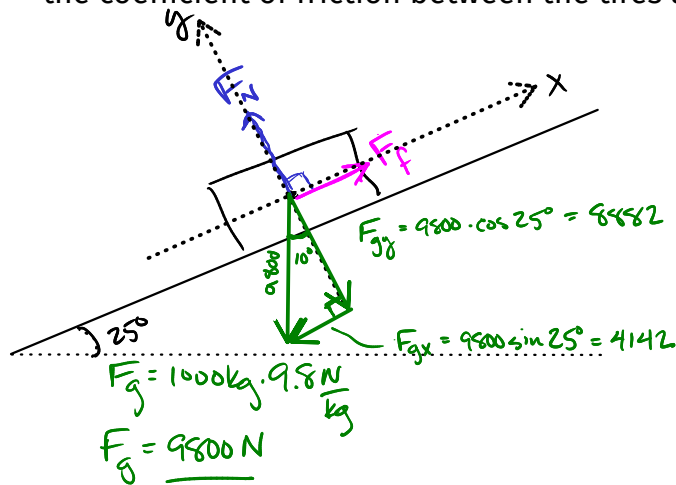
7. If I need to provide a 1000 N force to keep a 100 kg box moving at constant speed along a level floor, then what is the coefficient of friction between the floor and the box?

8. A 1000 kg car is parked on a hill that has an angle of  $10^\circ$  with respect to the horizontal. What is the weight of the car? What is the normal force on the car? What force is keeping the car from sliding down the hill? How large is that force?



	x	y
$F_g$	-1702	-9651
$F_N$	0	$F_N$
$F_f$	$F_f$	0
$\Sigma F$	0	0
$F_f = 1702 \text{ N}$		$F_N = 9651 \text{ N}$

9. If the maximum incline that the car can be parked on without sliding is  $25^\circ$ , then what is the coefficient of friction between the tires and the road?



	x	y
$F_g$	-4142	-8882
$F_N$	0	$F_N$
$F_f$	$F_f$	0
$\Sigma F$	0	0

$$F_f = 4142 \quad F_N = 8882$$

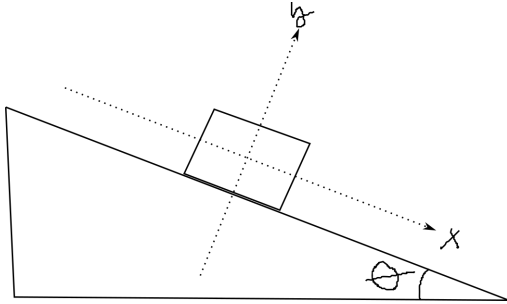
$$\mu = \frac{F_f}{F_N} = \frac{4142}{8882} = 0.47$$

10. Work the previous problem inside-out.

$$\mu = 0.47$$

$$\theta = ?$$

11. A 100 kg box slides down a friction-less inclined plane that has an angle of  $30^\circ$  to the horizontal. What is the net force on the box and then what is the acceleration of the box?

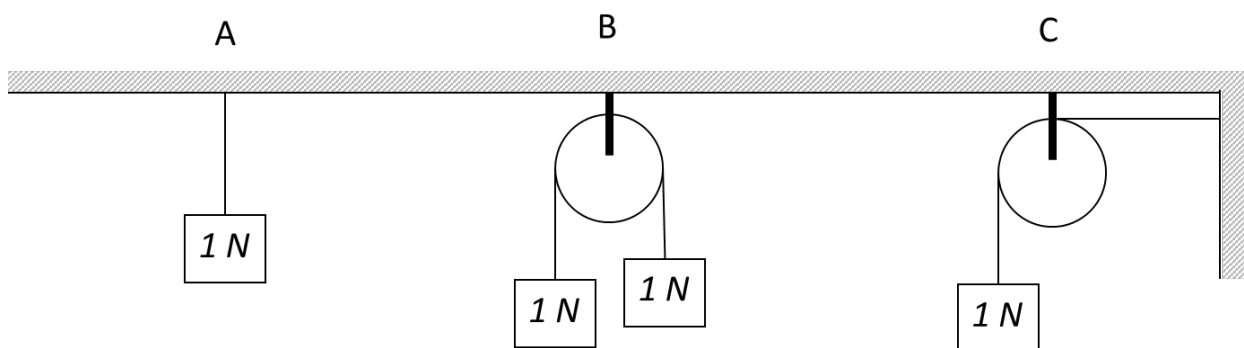


12. A 100 kg box slides down a friction-full inclined plane that has an angle of  $30^\circ$  to the horizontal and a coefficient of friction of  $\mu = 0.1$ . What is the net force on the box and then what is the acceleration of the box?

13. Let's do the friction-less inclined plane problem *in general* for any mass and incline. Follow the same procedure as before but with the variable  $m$  for mass and  $\theta$  for incline angle. Find an expression for the net force on the mass as a function of  $\theta$  and for the acceleration as a function of  $\theta$ .
14. Now let's do the inclined plane with friction *in general*. Just like the previous problem, use  $m$  for mass,  $\theta$  for angle, and now use  $\mu$  as a variable for coefficient of friction. Find an expression for the acceleration of the mass as a function of  $\theta$ ,  $m$ , and  $\mu$ .

15. In order to *hold* a box on a friction-less inclined plane, that is kept motionless, what force would be necessary to do that? Is there a difference between the force to hold it motionless on the incline and the force to push it up the incline *at constant speed*?

16. A 50 kg weight is suspended in three different ways shown below. What is the tension in each rope?



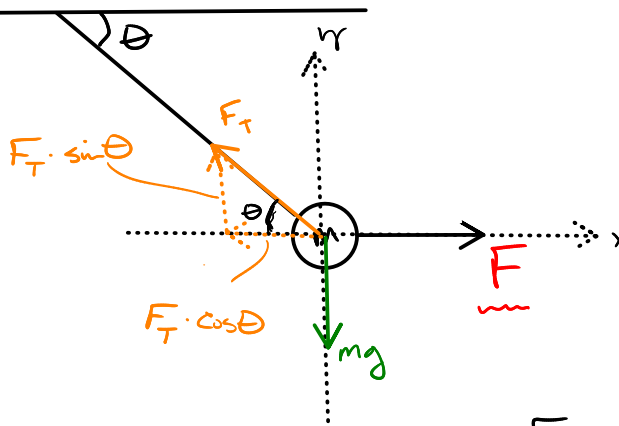
17. I am pulling two objects connected by a string. They are both 100 kg. There is no friction between the objects and the surface, and they are accelerating at  $1 \text{ m/s}^2$ . What is my pulling force and what tension force is between the boxes?

18. One object  $m_1$  connected by a string to another object  $m_2$  that is hanging off the edge of the table. There is a pulley at the edge of the table so the string is not introducing any friction to the system. If this is a friction-less table, then what is an expression for the acceleration of the objects?



19. Now do the previous problem again, but with a coefficient of friction  $\mu$  between the sliding mass ( $m_1$ ) and the surface.

9) + 10)

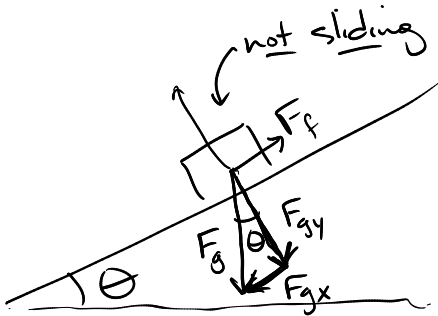


	x	y
$F_g$	0	$-mg$
$F$	$F$	0
	$F_T - F_T \cos \theta$	$F_T \sin \theta$
$F_{NET}$	0	0

$$F - F_T \cos \theta = 0 \quad | \quad -mg + F_T \sin \theta = 0$$

$$F_T = \frac{mg}{\sin \theta}$$

#5)



$$F_{gx} = F_g \sin \theta$$

$$F_{gy} = F_g \cos \theta$$

$\mu_s$

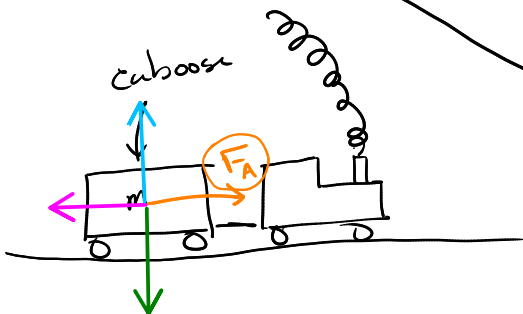
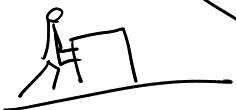
$$F_{fmax} = \mu_s F_N$$

$$F_f \leq \mu_s F_N$$

	x	y
$F_g$	$-F_{gx}$	$-F_{gy}$
$F_N$	0	$F_N$
$F_f$	$F_f$	0
$\Sigma F$	0	0

$$-F_{gx} + F_f = 0$$

$$F_f = F_{gx}$$



$$F_A + F_f = 2.1 \text{ N}$$

given  $F_A = ? \leftarrow$

	x	y
$F_A$	$F_A$	0
$F_g$	0	$-mg$
$F_N$	0	$F_N$
$F_f$	?	0
$\Sigma F$	$2.1 \text{ N}$	0

$F_f \leftarrow$  given

$$\Sigma F_x = ma_x$$

$$= 1 \text{ kg} (2.1 \text{ m/s}^2)$$

$$= \underline{2.1 \text{ N}} \quad 10$$