

At the end of this worksheet you should be able to

- discuss Newton's laws and provide examples of the application of each.
- discuss the quantities of displacement, velocity, and acceleration.
- 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 is the difference between mass and weight? Why can we use them interchangeably at the grocery store?

mass → amount of matter
weight → force of gravity

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

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

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

3. What is your mass in kg, your weight in Newtons, and your weight in lbs? Start with whichever one you know and convert to the others. If you don't want to use your weight, then make up a weight a person could be and do the same thing.

Handwritten calculation for mass conversion:

$$170 \text{ lbs} \times \frac{1 \text{ kg}}{2.2 \text{ lbs}} = 77.3 \text{ kg}$$

Labels: 170 lbs (customary force units), 1 kg (on earth), 2.2 lbs, 77.3 kg (metric mass).

Handwritten calculation for weight:

$$\text{weight} = \text{force of gravity} = m \cdot g$$

$$= 77.3 \text{ kg} \cdot 9.8 \frac{\text{N}}{\text{kg}} = 757 \text{ N}$$

Labels: in kg, on earth, 9.8 N/kg.

4. What is the force of gravity between the moon and the earth? You will need to look up some values.

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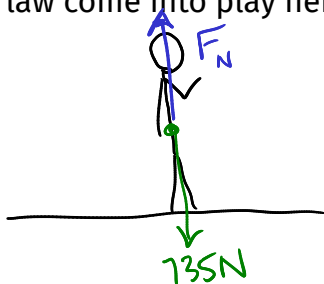
5. What is the force of gravity between two 75 kg people standing 1m apart?

OMIT FOR NOW

6. Find the radius from the center of the earth where Earth's gravitational field strength would
- $\frac{1}{2}$ of its value at the surface.
 - $\frac{1}{3}$ of its value at the surface.
 - What would be the *altitude* where the gravitational field is $\frac{1}{4}$ its value at the surface?
 - What is the gravitational field strength at the altitude that the space station orbits the earth?

OMIT FOR NOW

7. What is the normal force on a 75 kg person standing on the floor? Where does Newton's first law come into play here?



	x	y
F_g	0	-735N
F_N	0	F_N
	0	0

$$-735\text{N} + F_N = 0$$

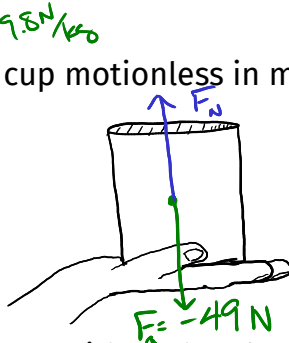
$$\underline{F_N = 735\text{N}}$$

← Newton's 1st Law

8. If the person from the previous problem jumped, by exerting a 10 000 N force on the floor (in addition to their weight) then what is the normal force from the floor on the person?

OMIT FOR NOW

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

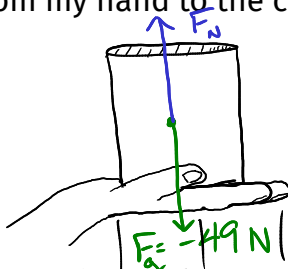


	x	y
F_g	0	-49N
F_N	0	F_N
ΣF	0	0

$$F_N - 49\text{N} = 0$$

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

10. 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?



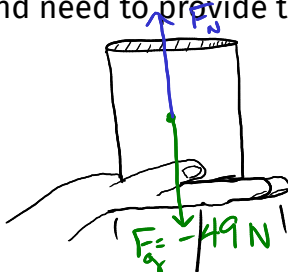
	x	y
F_g	0	-49N
F_N	0	F_N
ΣF	0	0

$$F_N - 49\text{N} = 0$$

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

constant speed means $a = 0$
 $\Sigma F = 0$

11. 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?



$$\Sigma F_y = m \cdot a_y$$

$$= 5\text{ kg} \cdot (+1\text{ m/s}^2)$$

$$\Sigma F_y = +5\text{N}$$

	x	y
F_g	0	-49N
F_N	0	F_N
ΣF	0	5N

$$-49\text{N} + F_N = +5\text{N}$$

$$\underline{\underline{F_N = 54\text{N}}}$$

12. If I accelerate the cup downwards with an acceleration of -1 m/s^2 , then what force does my hand need to provide to the cup?



$$\Sigma F_y = m a_y$$

$$\Sigma F_y = 5\text{ kg} \cdot (-1\text{ m/s}^2)$$

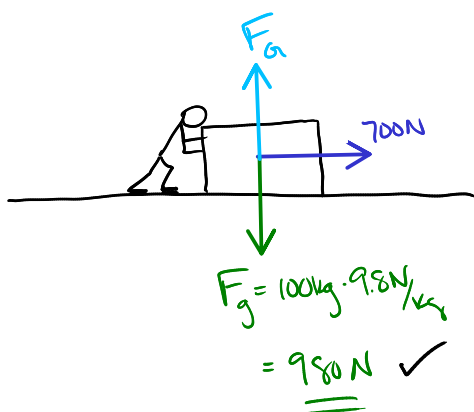
$$= -5\text{N}$$

	x	y
F_g	0	-49N
F_N	0	F_N
ΣF	0	-5N

$$-49\text{N} + F_N = -5\text{N}$$

$$\underline{\underline{F_N = +44\text{N}}}$$

13. 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.



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

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

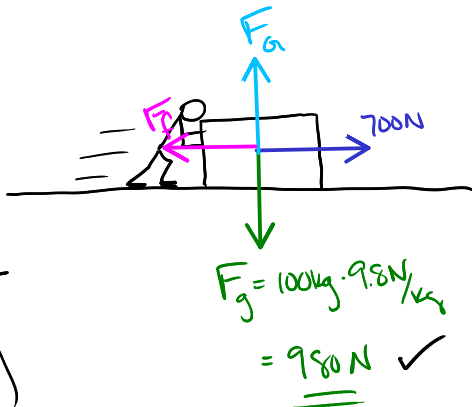
Bonus: What is the acceleration?

$$\Sigma F_x = m a_x$$

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

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

$$\mu = \frac{|F_f|}{|F_N|}$$



$$|F_f| = \mu |F_N|$$

$$|F_f| = 0.5 \cdot (980\text{N})$$

$$|F_f| = 490\text{N}$$

$$F_g = 100\text{kg} \cdot 9.8\text{N/kg}$$

$$= 980\text{N} \checkmark$$

Bonus: What is the acceleration?

$$\Sigma F_x = ma_x \Rightarrow 210\text{N} = 100\text{kg} \cdot a_x$$

$$a_x = +2.1\text{m/s}^2$$

vector
addition

	x	y
F_g	0	-980N
F_N	0	F_N
F_A	+700N	0
F_f	-490N	0
	+210N	0

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

"observation"

$$0\text{m/s}^2 = a_y \Rightarrow \Sigma F_y = 0$$

15. In order to keep a box moving at constant speed along a friction-less level surface, what pushing force is required?

DN

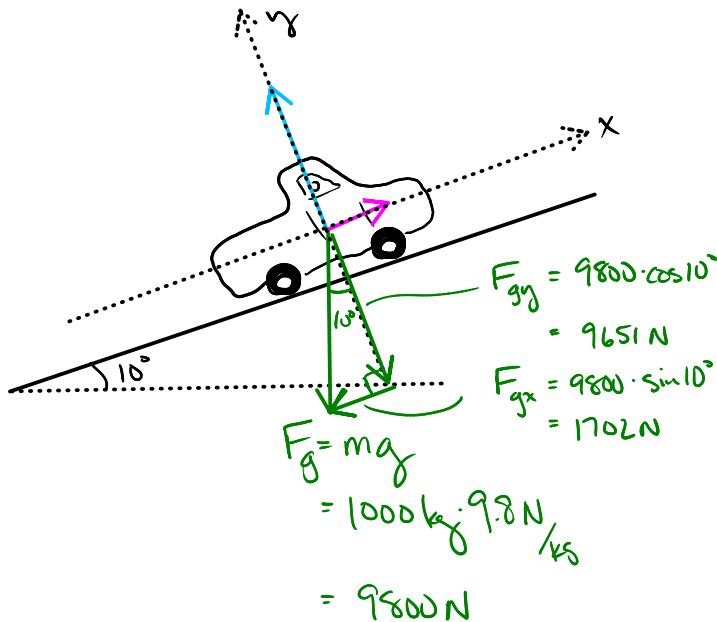
16. If I have to exert a force to keep a box moving along a level surface at constant speed, then what other force is probably present? What is the net force on the box in this case?

friction

DN

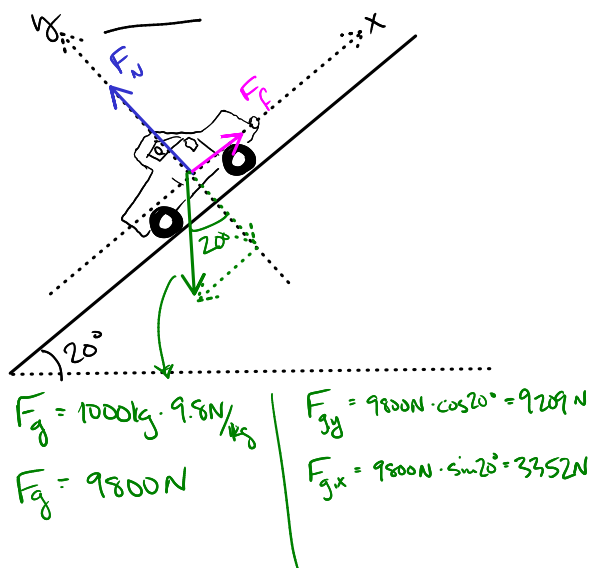
17. If I need to provide a 1000 N force to keep a 100 kg box moving at constant speed along a level floor, then what is the coefficient of friction between the floor and the box?

18. A 1000 kg car is parked on a hill that has an angle of 10° 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	$F_N = +9651$
F_N	0	F_N	$F_f = +1702 \text{ N}$
F_f	F_f	0	
ΣF	0	0	

19. If the hill that the car is parked on from the previous problem is somehow made steeper to a 20° incline, what is the normal force and the frictional force on the car now? It is still motionless.



	X	Y	
F_g	-3352	-9209	$F_N = +9209 \text{ N}$
F_N	0	F_N	$F_f = +3352 \text{ N}$
F_f	F_f	0	
ΣF	0	0	

$$F_f \leq \mu_s F_N$$

20. If the maximum incline that the car can be parked on without sliding is 25° , then what is the coefficient of friction between the tires and the road?

inside-out
 $\mu = 0.47$
 $\theta = ?$

$F_g = 1000 \text{ kg} \cdot 9.8 \text{ N/kg}$
 $F_g = 9800 \text{ N}$
 $F_{gy} = 9800 \text{ N} \cdot \cos 25^\circ = 8882 \text{ N}$
 $F_{gx} = 9800 \text{ N} \cdot \sin 25^\circ = 4142 \text{ N}$

X	Y
$F_g - 4142$	-8882
F_N	F_N
F_f	0
ΣF	0

$F_N = +8882 \text{ N}$
 $F_f = +4142 \text{ N}$

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

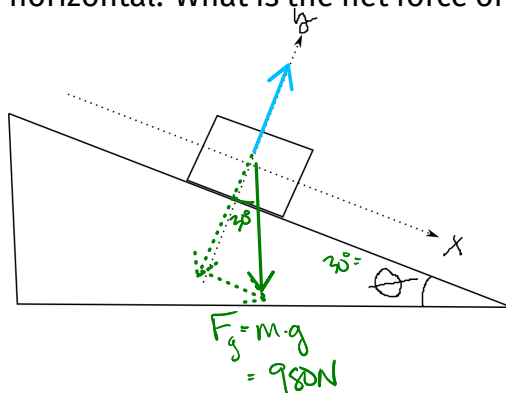
X	Y
$F_g - 9800 \sin \theta$	$-9800 \cos \theta$
F_N	F_N
F_f	0
ΣF	0

$F_g = 1000 \text{ kg} \cdot 9.8 \text{ N/kg}$
 $F_g = 9800 \text{ N}$
 $F_{gy} = 9800 \text{ N} \cdot \cos \theta$
 $F_{gx} = 9800 \text{ N} \cdot \sin \theta$

$F_N = 9800 \cos \theta$
 $F_f = 9800 \sin \theta$

$\mu = 0.47 = \frac{F_f}{F_N}$
 $0.47 = \frac{9800 \cdot \sin \theta}{9800 \cdot \cos \theta}$
 $0.47 = \frac{\sin \theta}{\cos \theta} = \tan \theta$
 $0.47 = \tan \theta$
 $\theta = \tan^{-1}(0.47)$
 $\theta = 25^\circ$

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



X	Y
$F_g + 490 \text{ N}$	-849 N
F_N	F_N
$\Sigma F: +490 \text{ N}$	0

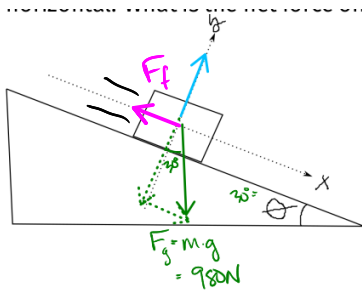
"observe"

$$\Sigma F_x = m a_x$$

$$+490 \text{ N} = (100 \text{ kg}) \cdot a_x$$

$$a_x = +4.9 \text{ m/s}^2$$

22. A 100 kg box slides down a friction-full inclined plane that has an angle of 30° 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?



x	y
$F_g + 490 \text{ N}$	-849 N
F_N	0
$F_f - 84.9$	0
ΣF 405.1 0	

$$F_N = +849 \text{ N}$$

$$F_f = \mu F_N$$

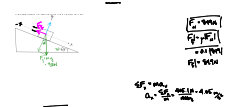
$$F_f = 0.1 \cdot 849 \text{ N}$$

$$= 84.9 \text{ N}$$

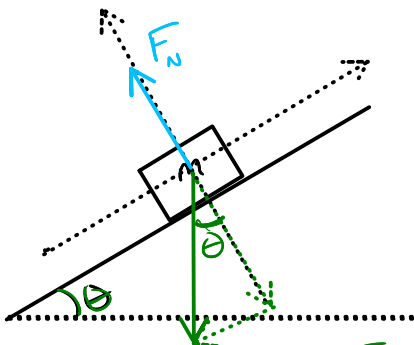
$$\Sigma F_x = ma_x$$

$$405.1 = 100 \cdot a_x$$

$$a_x = 4.05 \text{ m/s}^2$$



23. 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 θ for incline angle. Find an expression for the net force on the mass as a function of θ and for the acceleration as a function of θ .



$$F_g = mg$$

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

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

x	y
$F_g - mg \sin \theta$	$-mg \cos \theta$
F_N	0
ΣF $-mg \sin \theta$ 0	

$$-mg \cos \theta + F_N = 0$$

$$F_N = mg \cos \theta$$

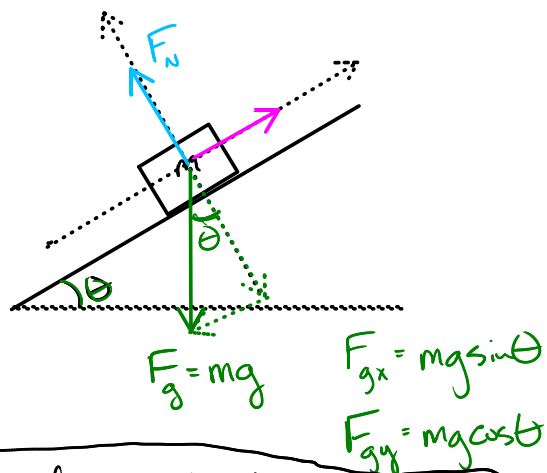
$$\Sigma F_x = ma_x$$

$$-mg \sin \theta = ma_x$$

$$a_x = \frac{-mg \sin \theta}{m}$$

$$a_x = -g \sin \theta$$

24. Now let's do the inclined plane with friction *in general*. Just like the previous problem, use m for mass, θ for angle, and now use μ as a variable for coefficient of friction. Find an expression for the acceleration of the mass as a function of θ , m , and μ .



	x	y	
F_g	$-mg \sin \theta$	$-mg \cos \theta$	$F_N = +mg \cos \theta$
F_N	0	F_N	
F_f	$\mu mg \cos \theta$	0	$ F_f = \mu \cdot F_N $ $F_f = \mu mg \cos \theta$
ΣF	$-mg \sin \theta + \mu mg \cos \theta$	0	

$$\frac{-mg \sin \theta + \mu mg \cos \theta}{m} = \frac{ma_x}{m}$$

$$a_x = -g \sin \theta + \mu g \cos \theta$$

$$|a_x = g(\mu \cos \theta - \sin \theta)|$$

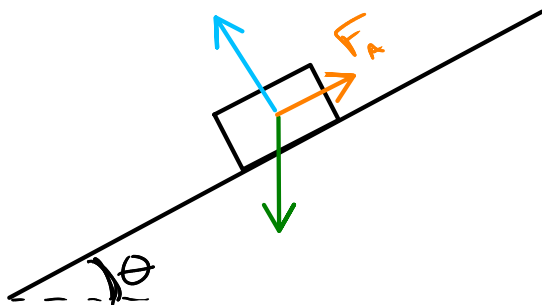
Where is the acceleration $a_x = 0$?

$$0 = g(\mu \cos \theta - \sin \theta)$$

$$0 = \mu \cos \theta - \sin \theta \Rightarrow \sin \theta = \mu \cos \theta$$

$$\frac{\sin \theta}{\cos \theta} = \tan \theta = \mu$$

25. In order to *hold* a box on a friction-less inclined plane, that is ~~keep it~~ ^{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?



	x	y
F_g	$-mg \sin \theta$	$-mg \cos \theta$
F_N	0	F_N
F_A	F_A	0
ΣF	0	0

$$\Sigma F = ma \rightarrow F_A = mg \sin \theta$$

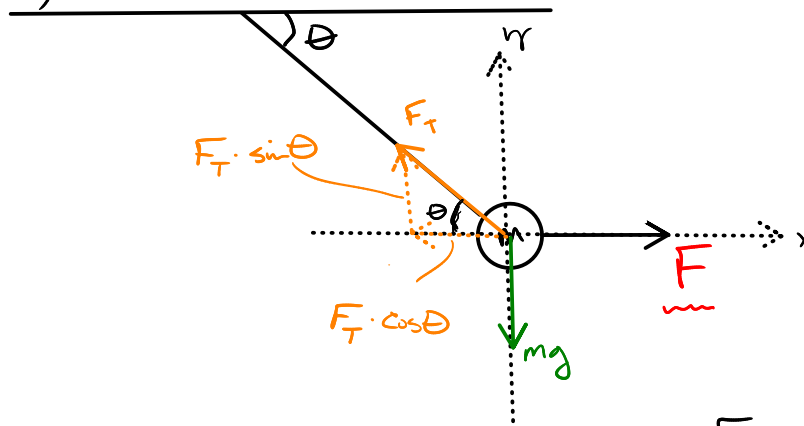
26. What is a displacement? What is velocity? What is acceleration? How do you know you have moved places or how do you know you are in motion? How do you know you are accelerating?

27. If I go from $x = 10 \text{ m}$ to $x = 28 \text{ m}$, then what is my displacement? If it takes 12 seconds to do that, then what is my average velocity over that interval. Does this mean that my velocity has this value at every instant along the path?

28. If I am initially going $+10 \text{ m/s}$ and it takes me 15 seconds to speed up to $+25 \text{ m/s}$, then what is my acceleration?

29. If my acceleration is $+10 \text{ m/s}^2$, then if I started at rest, how long would it take me to speed up to $+45 \text{ m/s}$? How fast would I be going after 10 seconds?

9) + 10)

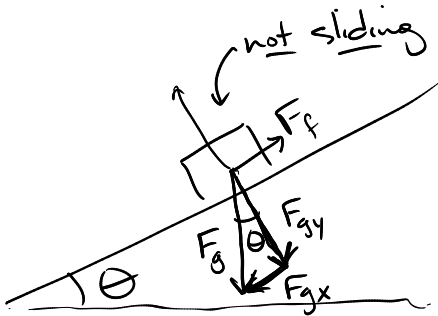


	x	y
F_g	0	$-mg$
F	F	0
F_T	$F_T \cos \theta$	$F_T \sin \theta$
F_{NET}	0	0

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

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

#5)



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

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

μ_s

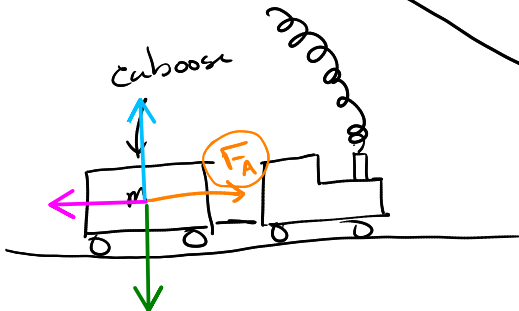
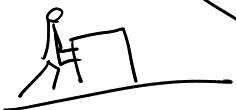
$$F_{fmax} = \mu_s F_N$$

$$F_f \leq \mu_s F_N$$

	x	y
F_g	$-F_{gx}$	$-F_{gy}$
F_N	0	F_N
F_f	F_f	0
ΣF	0	0

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

$$F_f = F_{gx}$$



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

$$F_A = ? \leftarrow$$

	x	y
F_A	F_A	0
F_g	0	$-mg$
F_N	0	F_N
F_f	?	0
ΣF	2.1 N	0

$F_f \leftarrow$ given

$$\Sigma F_x = ma_x$$

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

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