FORCES

IB PHYSICS | COMPLETED NOTES

Newton's 1st Law & Net Force

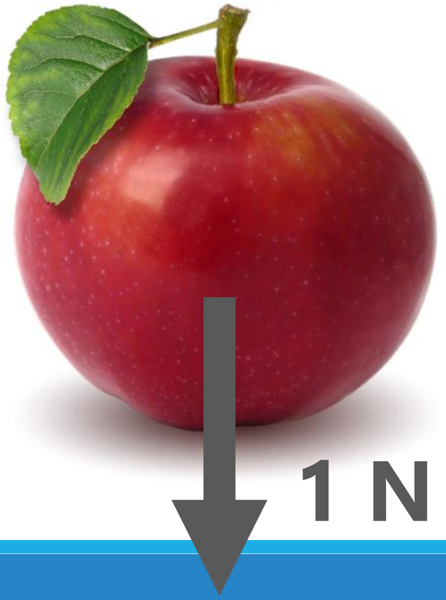
IB PHYSICS | FORCES

What is a Newton??

Unit of Force

$$N = kg \times m\ s^{-2}$$

*An apple weighs about 1 N



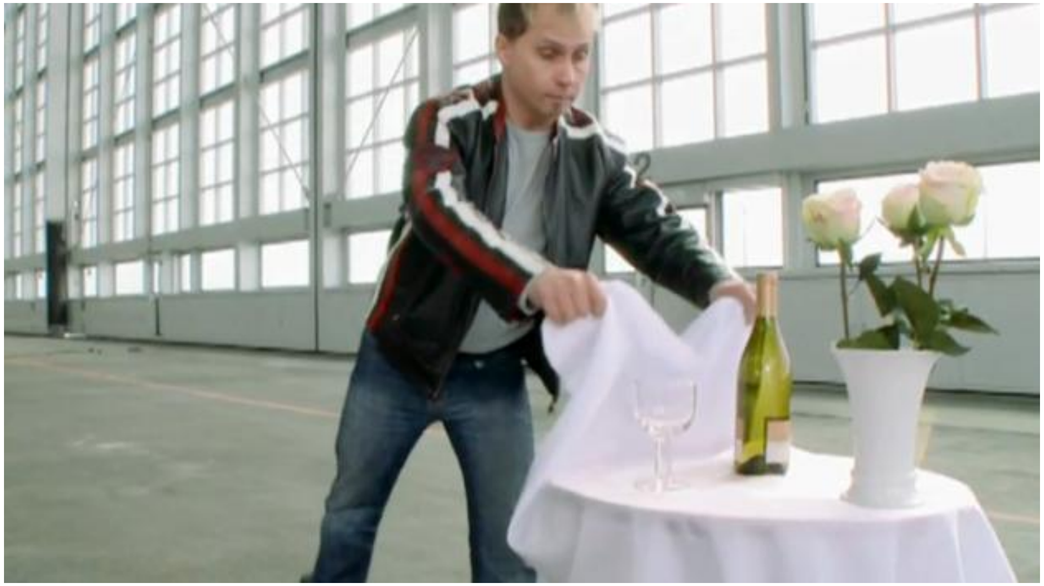
REMINDER: Vector vs Scalar

Vector Quantities	Scalar Quantities
Displacement	Distance
Velocity	Speed
Force	Energy
Can be negative to indicate direction	Only Positive

Newton's First Law

A body will remain at rest or moving with constant velocity unless acted upon by an unbalanced force

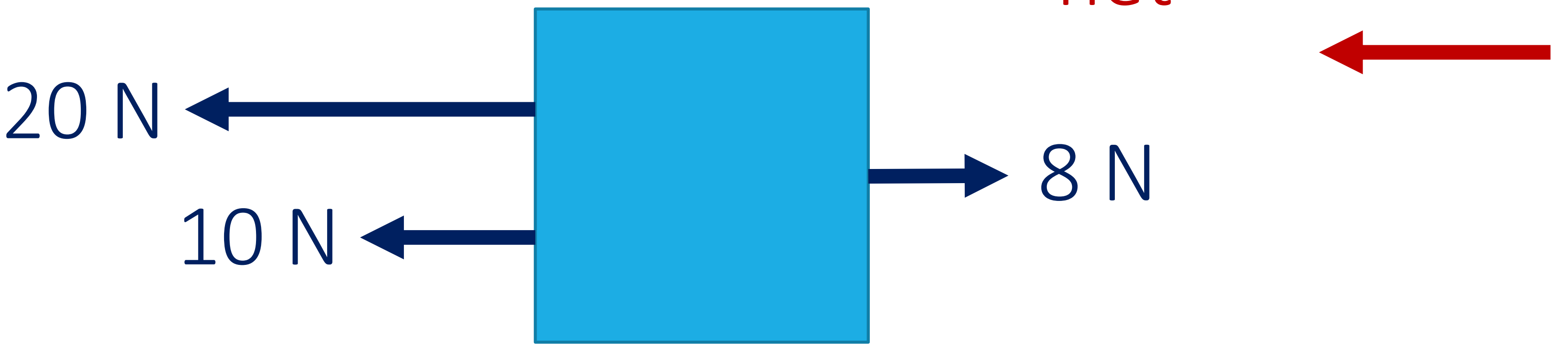
"Law of Inertia"



(Total) → Net Force

The vector sum of all the forces acting on an object

$F_{net} = 22\ N$

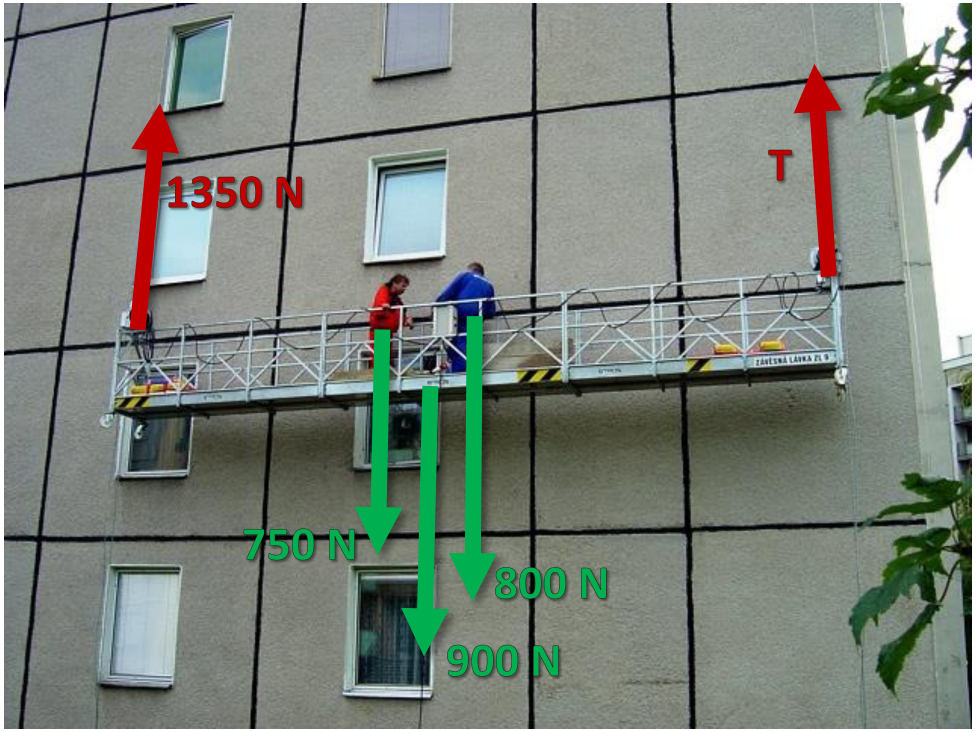


Equilibrium

When all forces cancel out, the object is in equilibrium

$F_{net} = 0\ N$

Using Equilibrium



What is the tension force on the second cable if the window washers are in equilibrium?

$$F_{net} = 0 \text{ N}$$

$$1350 + T - 750 - 900 - 800 = 0 \text{ N}$$

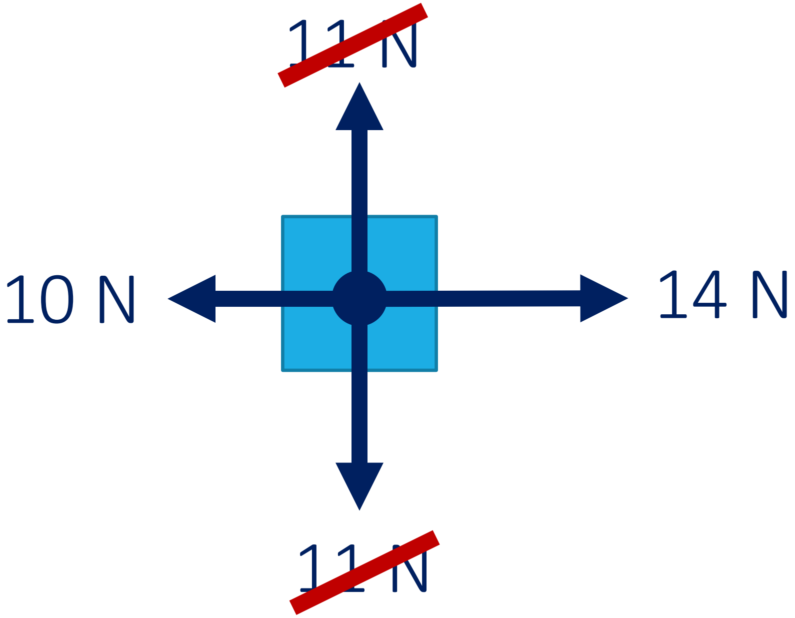
$$T = 1100 \text{ N}$$

Weight of Guy #1 = 750 N

Weight of Guy #2 = 800 N

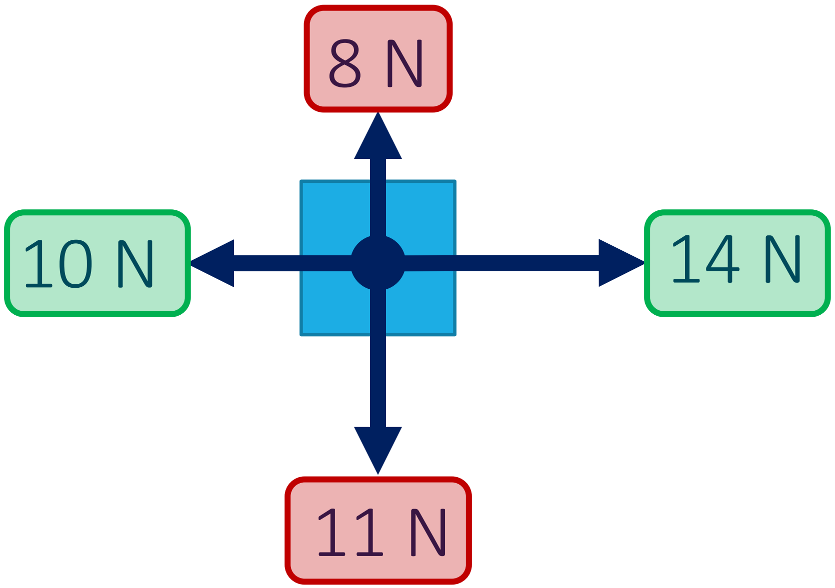
Weight of Platform = 900 N

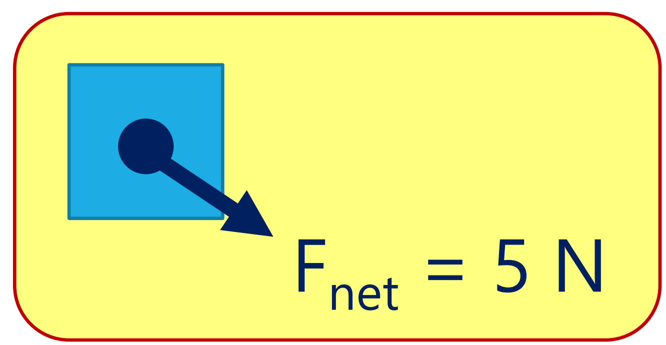
What is the Net Force? | 1



$F_{net} = 4\ N$ →

What is the Net Force? | 2



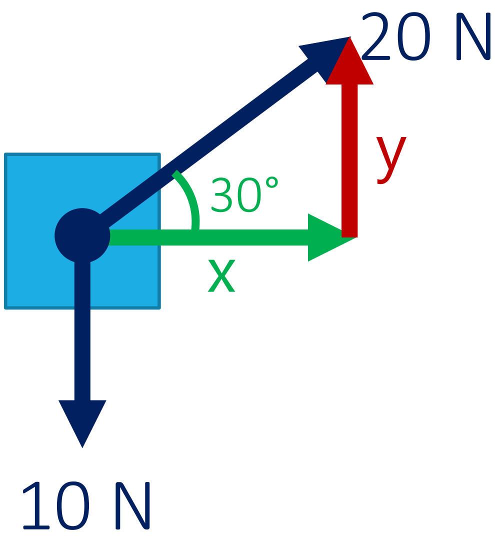


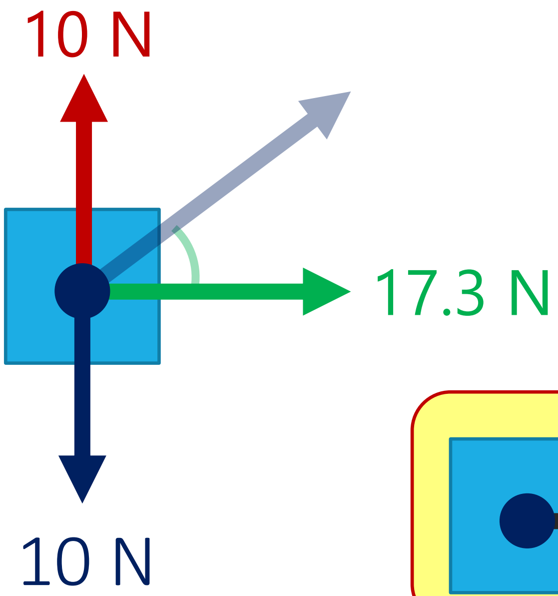
What is the Net Force? | 3

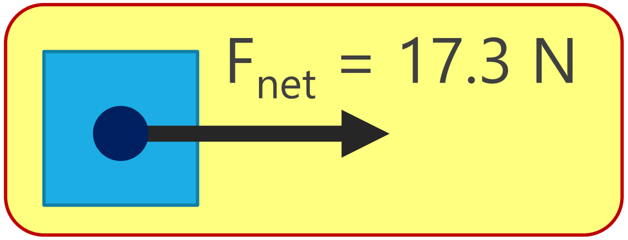
Remember SOHCAHTOA?

$x = 20\cos(30) = 17.3\text{ N}$

$y = 20\sin(30) = 10\text{ N}$



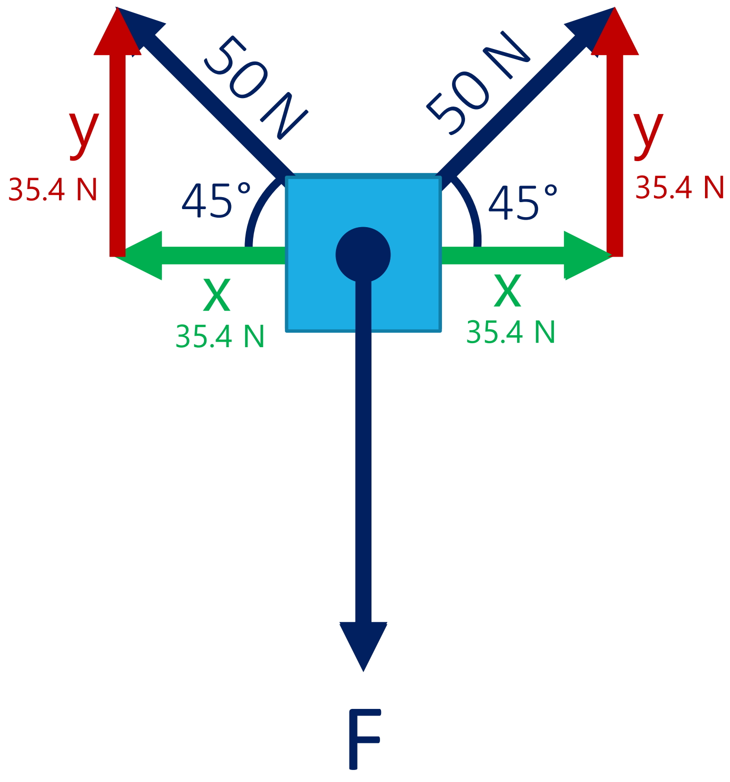


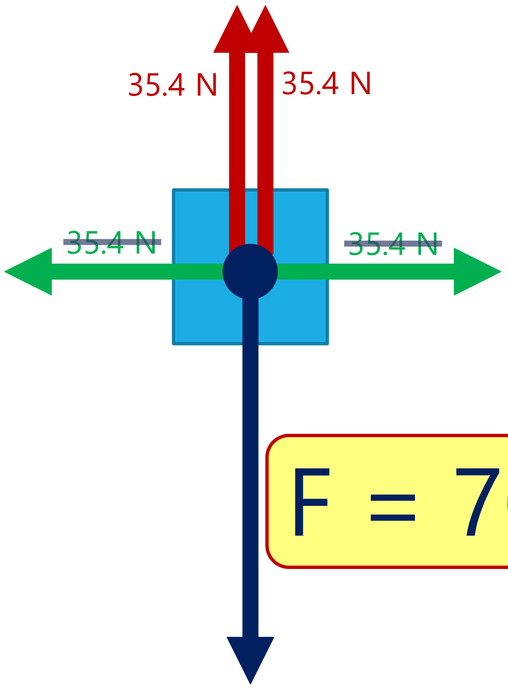


What is the Missing Force?

x = 50 cos(45) = 35.4 N y = 50 sin(45) = 35.4 N

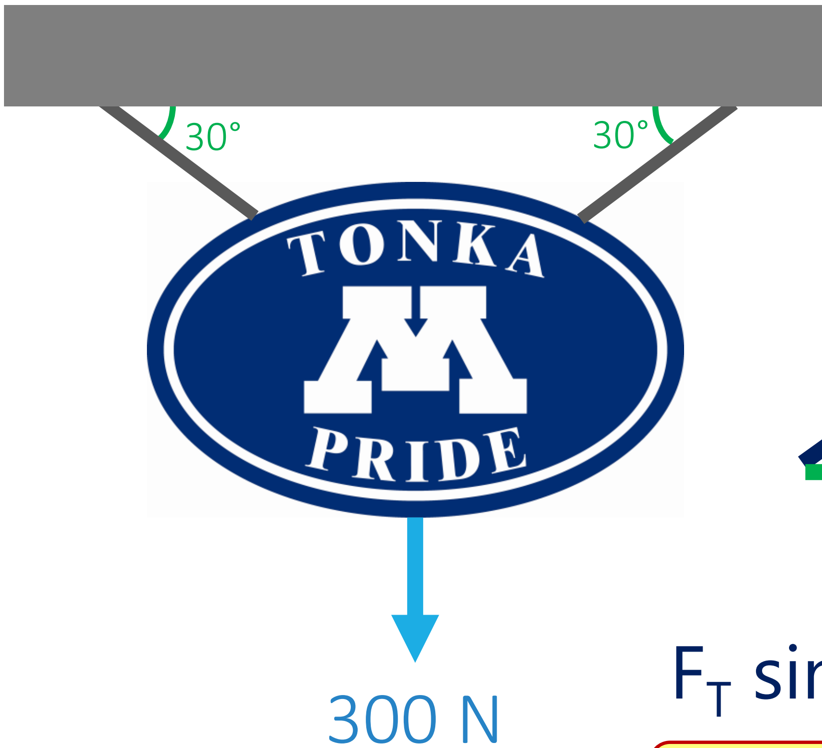
$F_{net} = 0\ N$





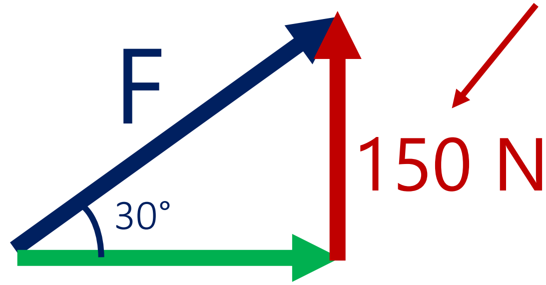
F = 70.8 N

Cable Tension



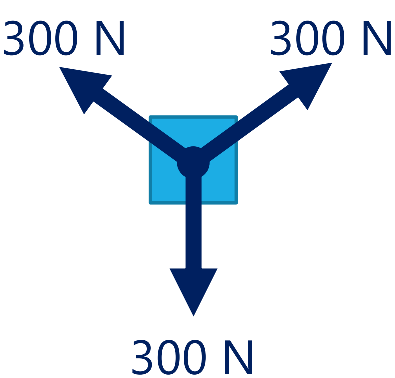
What is the tension of these cables?

Each cable must support half the vertical force if the weight is evenly distributed



$$F_T \sin(30) = 150\text{ N}$$

$$F_T = 300\text{ N}$$



Lesson Takeaways

- ❑ I can define a force (with proper units) in terms of the interaction between two objects
- ❑ I can describe Newton's first law
- ❑ I can calculate the net force on an object
- ❑ I can calculate an unknown force for an object in equilibrium

Newton's 2nd Law

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What is Momentum?

An object's tendency to continue moving

$$\text{Momentum} = m \times v$$

Newton's Second Law

The rate of change of momentum of a body is directly proportional to the unbalanced force acting on that body and takes place in same direction.

$$F_{net} = \frac{mv - mu}{t} = m\left(\frac{v - u}{t}\right) = ma$$

$$v = u + at$$

$$a = \frac{v - u}{t}$$

$$F_{net} = ma$$

Newton's Second Law

Force = mass × acceleration

Symbols

$$F = m \times a$$

Units

Newton → N

$$N = kg \times m\ s^{-2}$$

2nd Law | Try This… | #1

Your shiny new motorcycle has an engine capable of 2450 N of force. If it has a max acceleration of 15 m s^{-2}, what is its mass in kilograms?

$$F = 2450\ \mathrm{N}$$

$$a = 15\ \mathrm{m\ s^{-2}}$$

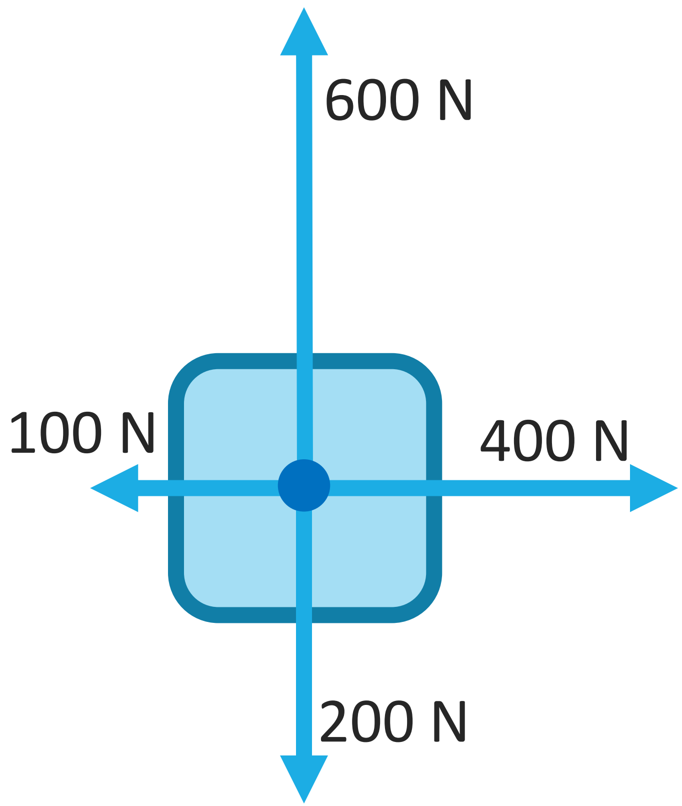
$$F = ma$$

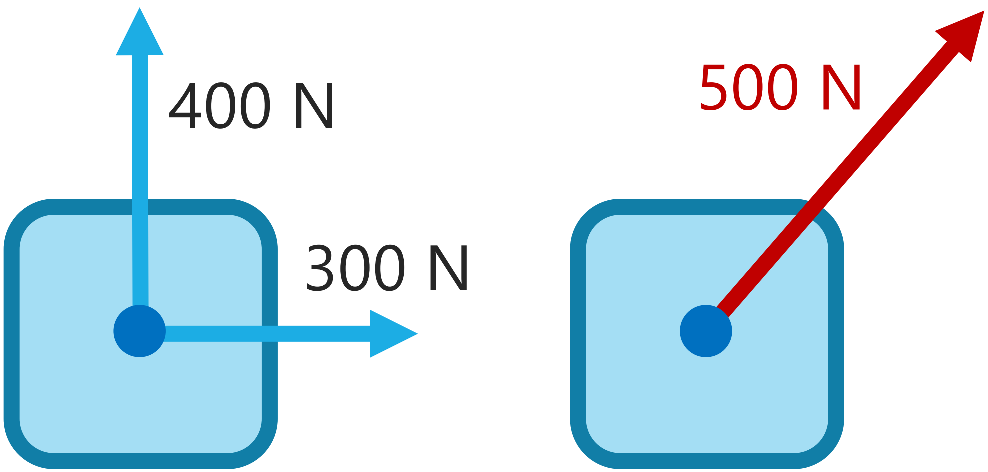
$$m = \frac{F}{a} = \frac{2450}{15}$$

$$m = 163\ \mathrm{kg}$$

2nd Law | Try This… | #2

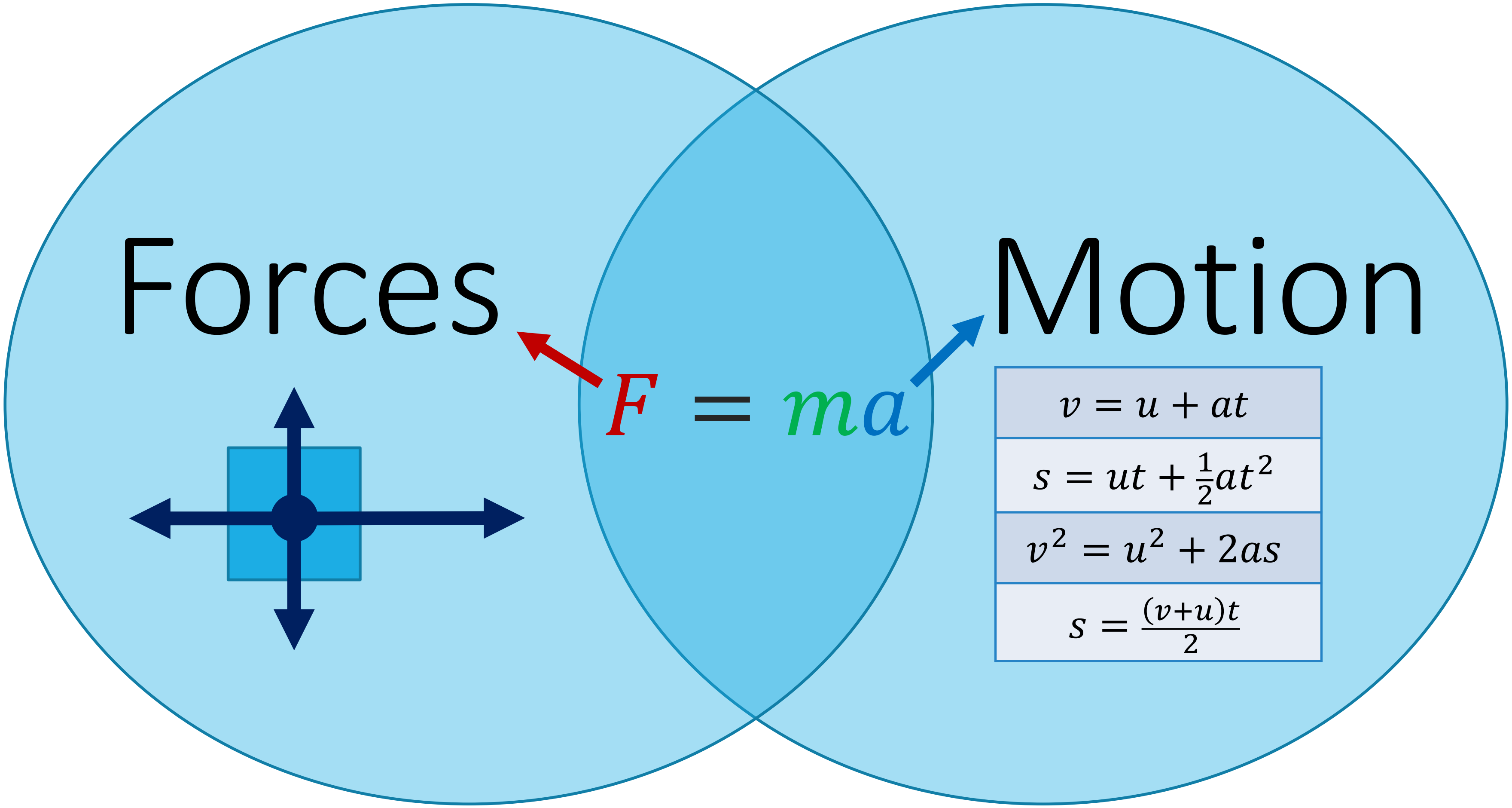
How fast is this 100 kg block accelerating?





$$a = \frac{F}{m} = \frac{500\text{ N}}{100\text{ kg}} = \mathbf{5\ m\ s^{-2}}$$

2nd Law is the Bridge



Equations

Units	*m*	*m s*$^{-1}$	*m s*$^{-1}$	*m s*$^{-2}$	*s*
$v = u + at$		u	v	a	t
$s = ut + \frac{1}{2}at^2$	s	u		a	t
$v^2 = u^2 + 2as$	s	u	v	a	
$s = \frac{(v+u)t}{2}$	s	u	v		t

2^{nd} Law | Try This… | #3

A race car has a mass of 710 kg. It starts from rest and travels 40 meters in 3.0 seconds. That car is uniformly accelerated during the entire time. What net force is applied to it?

s	40 m
u	0 m s^{-1}
v	---
a	?
t	3 s

$$s = \cancel{ut} + \frac{1}{2}at^2$$

$$40 = \frac{1}{2}(a)(3)^2$$

$$\boxed{a = 8.89 \text{ m } s^{-2}}$$

$$F = ma$$

$$F = (710)(8.89)$$

$$\boxed{F = 6311 \text{ N}}$$

2^{nd} Law | Try This… | #4

You slide a 0.20 kg hockey puck on the ice at a velocity of 12 m s^{-1}. After 3 seconds, the force of friction causes it to stop. What is the force of friction?

s	---
u	12 m s^{-1}
v	0 m s^{-1}
a	?
t	3 s

$$v = u + at$$

$$0 = 12 + a(3)$$

$$a = -4 \text{ m } s^{-2}$$

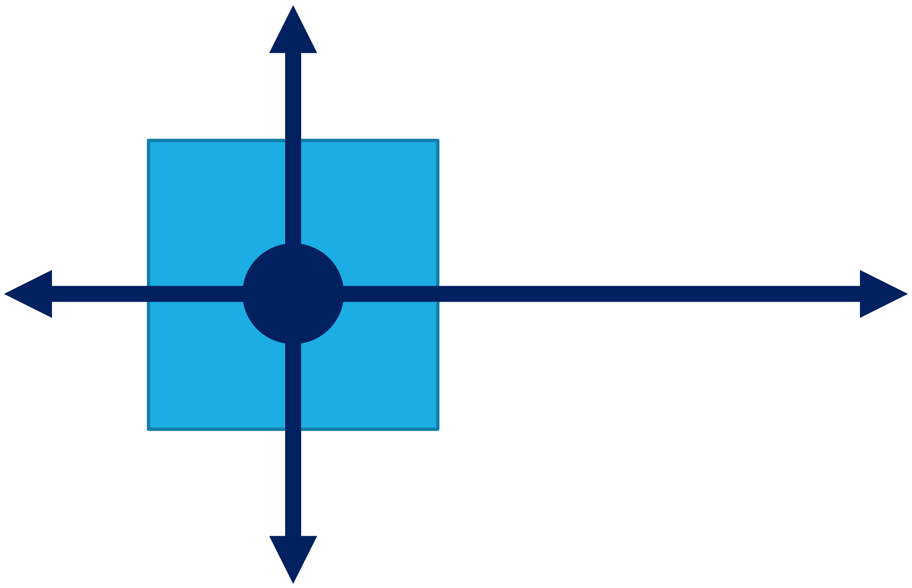
$$F = ma$$

$$F = (0.2)(-4)$$

$$F = -0.8 \text{ N}$$

Net Force → Acceleration

Any time there is a net force that is not zero, there will be acceleration in that direction



$$a = \frac{F}{m}$$

Equilibrium → Acceleration = 0

If the net force is 0 N, then the object is not accelerating.

This can mean two different things:

- Not Moving
- Constant Velocity

Lesson Takeaways

- ❑ I can describe Newton's second law in terms of momentum
- ❑ I can calculate force given mass and acceleration and calculate acceleration given force and mass
- ❑ I can combine Newton's second law with the kinematic equations to solve force/motion problems
- ❑ I can explain the connection between constant velocity and balanced forces

Weight, Normal Reaction, & Tension

IB PHYSICS | FORCES

Types of Forces | Weight

Newton's 2nd Law: $F = m \times a$

$\downarrow \quad \downarrow \quad \downarrow$

Weight: $F_g = m \times g$

F_g → Force of Gravity (weight) [N]

m → mass [kg]

g → Acceleration due to Gravity → 9.81 $m\ s^{-2}$

Mass vs Weight

Mass

Amount of matter

Metric Units	
Mass	**kg**
Weight	**N**

Weight

Force due to gravity

Types of Forces | Weight

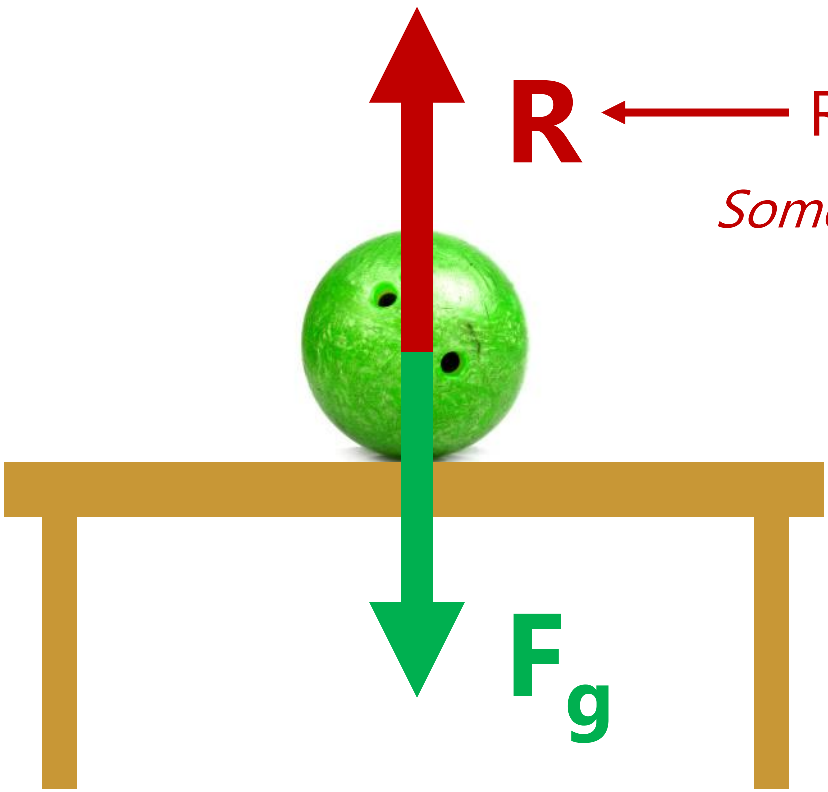
What is your mass in kilograms?   (1 kg = 2.2 lbs)

$$m = 165\ \text{lbs} \times \frac{1\ \text{kg}}{2.2\ \text{lbs}} = \mathbf{75\ kg}$$

What is your weight in Newtons?

$$F_g = mg = (75)(9.81) = \mathbf{736\ N}$$

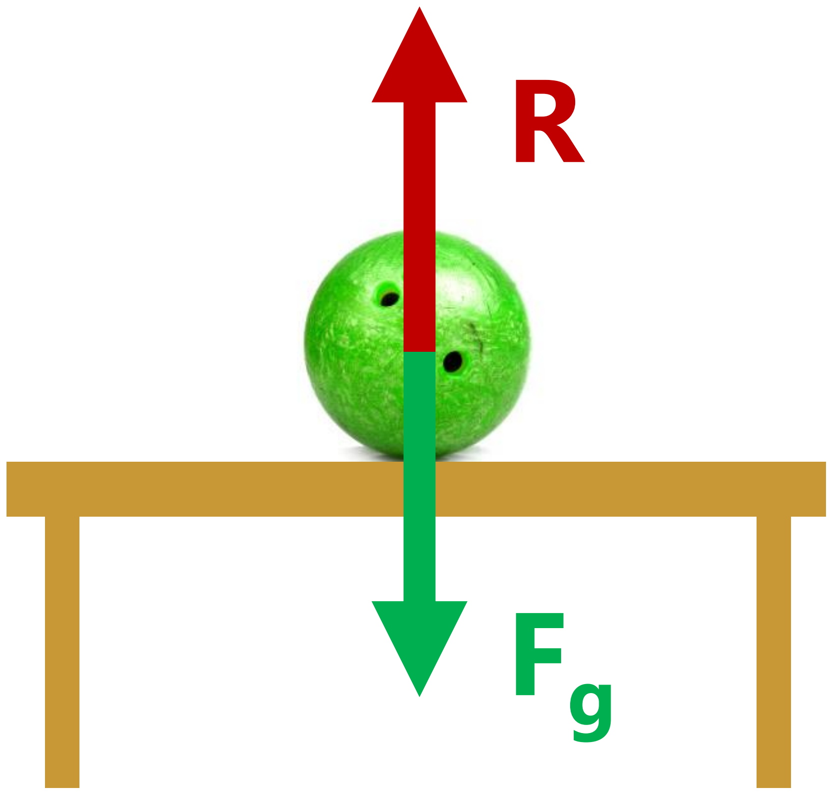
Types of Forces | Normal Reaction



R for normal **Reaction** force

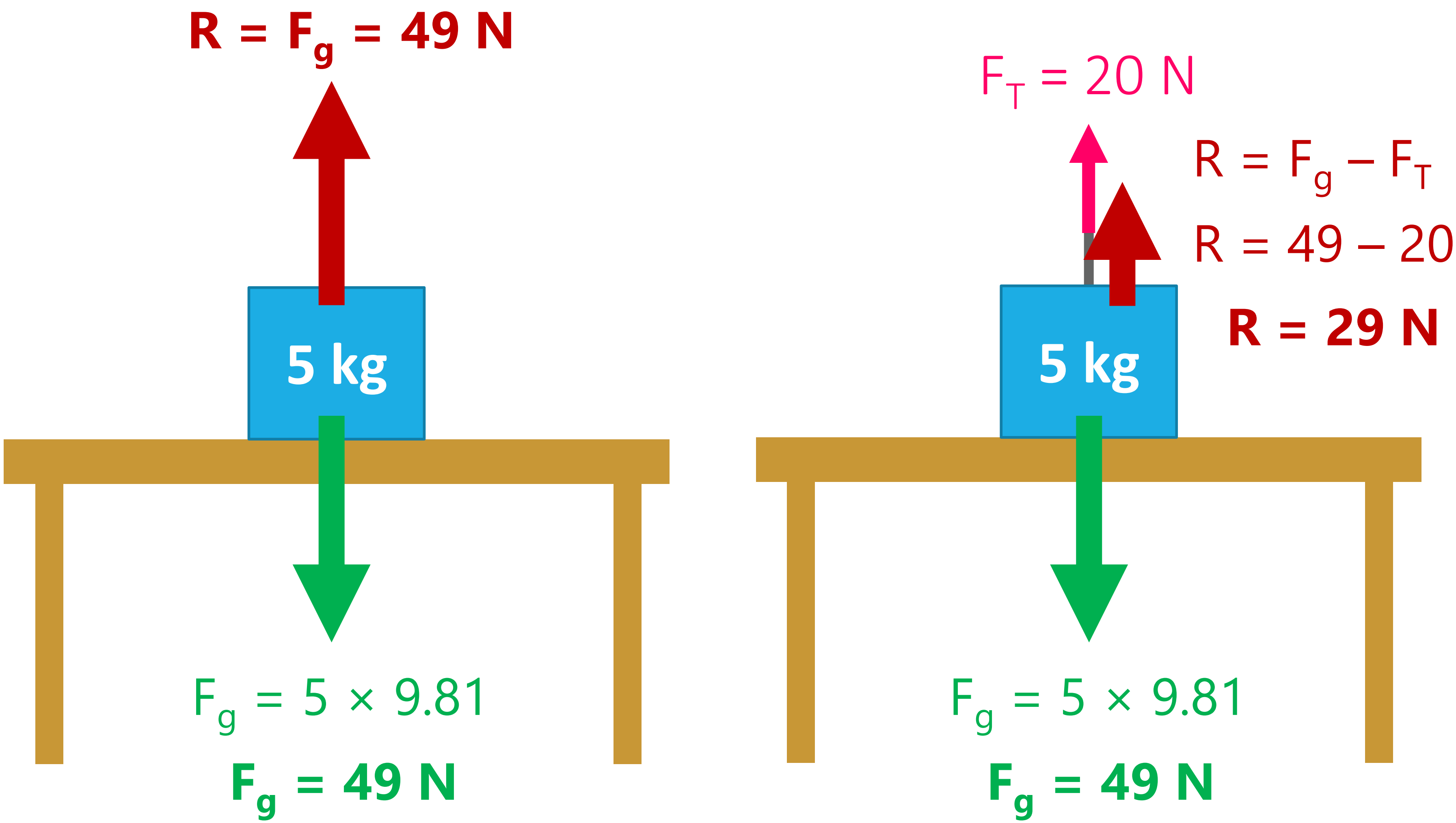
Some sources use F_N for "Normal Force"

Types of Forces | Normal Reaction

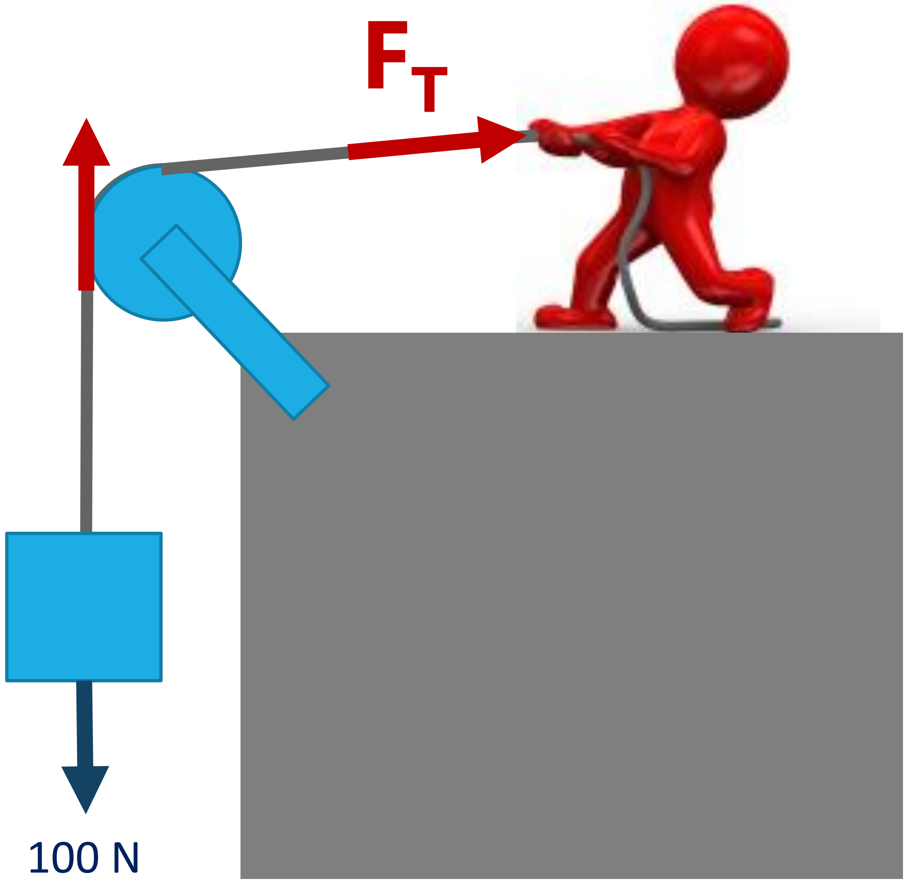


*Always perpendicular to the surface applying the force

Normal Force Depends on Scenario



Types of Forces | Tension



*Always pulls in the direction of the rope or chain

Lesson Takeaways

- ❑ I can calculate the weight of an object
- ❑ I can describe the difference between mass and weight
- ❑ I can use Newton's third law to describe how to find the normal reaction force with force pairs
- ❑ I can use a diagram to identify the direction of tension force acting on an object

Friction

IB PHYSICS | FORCES

Types of Forces | Friction

F_f

*Always opposes motion

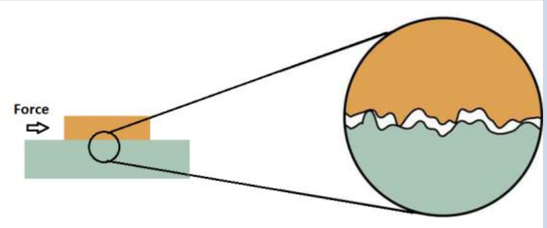
What is Friction?

The force ___opposing___ the motion between two objects that are in ___contact___.

Types of Friction

Static Friction-

Not Moving



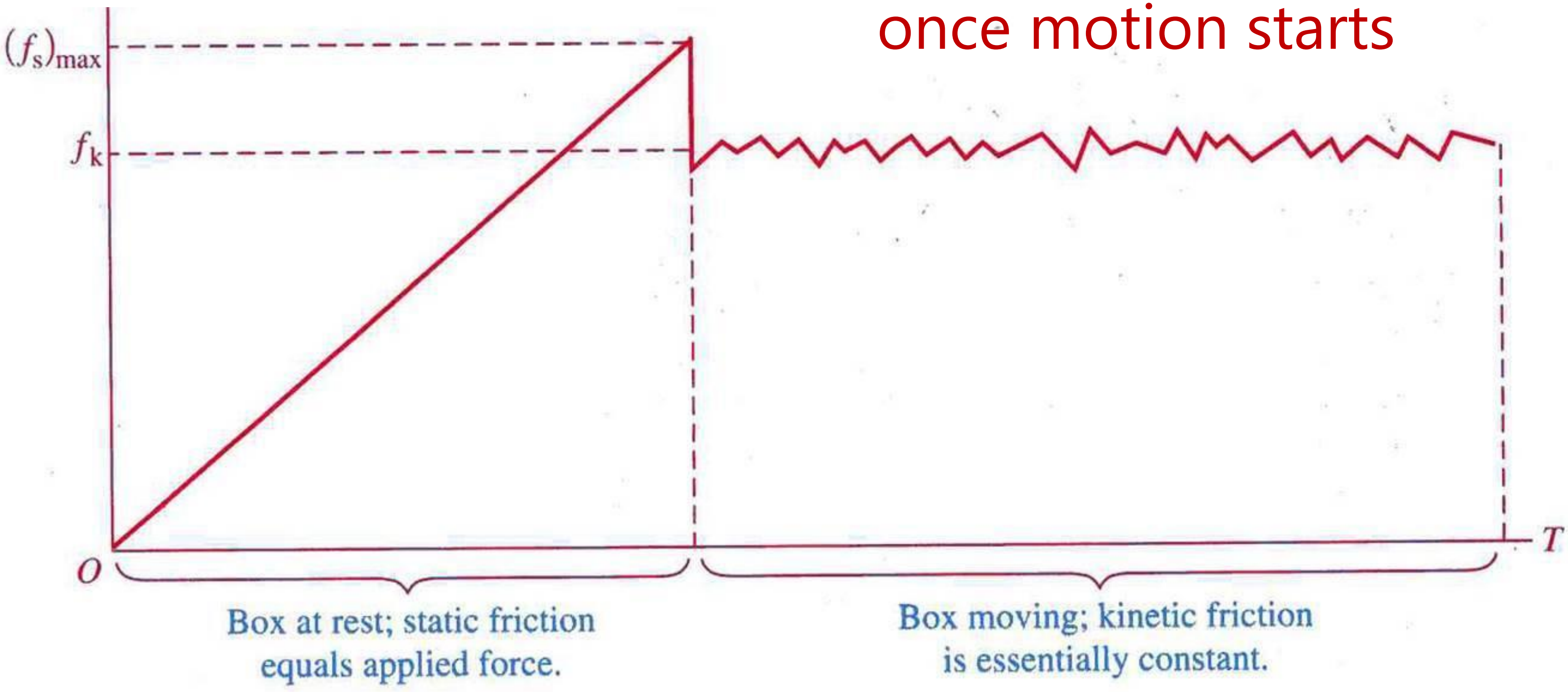
Dynamic (Kinetic) Friction-

In Motion

Static > Dynamic

Static vs. Dynamic Friction

Friction decreases once motion starts



How do we Calculate Friction?

$$F_f = \mu \times R$$

← Normal Reaction Force

↑ Coefficient of Friction

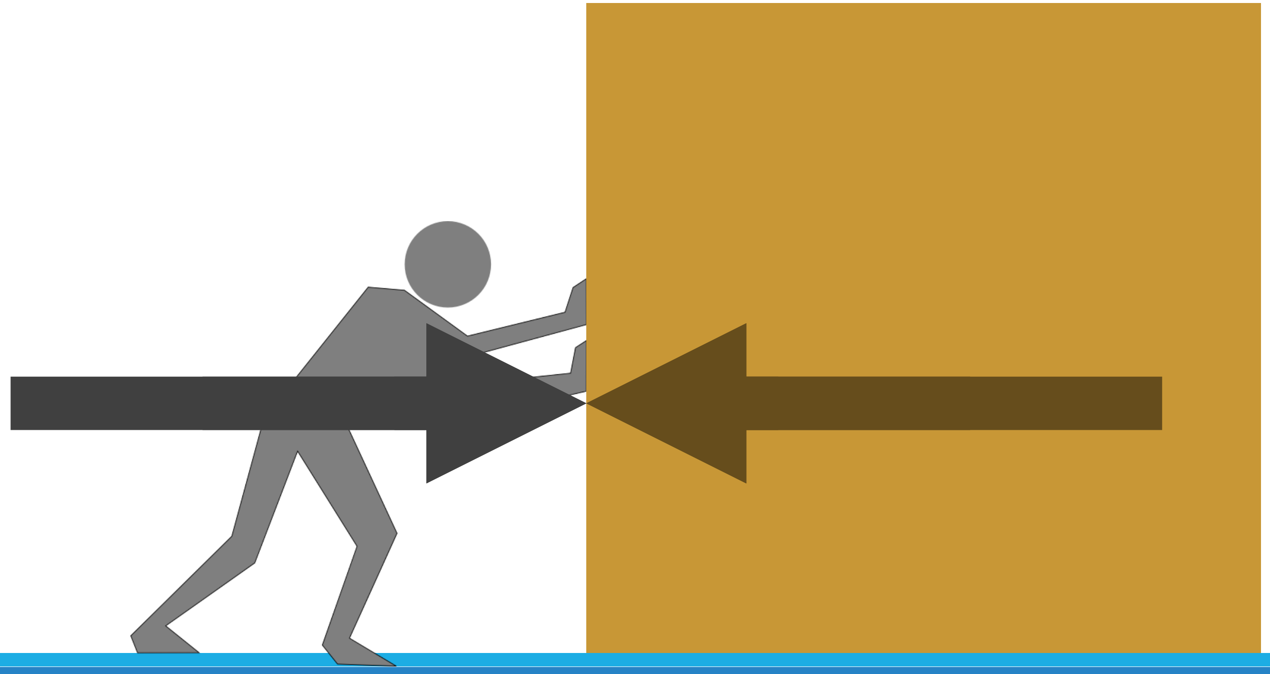
**unitless*

Materials	μ_s	μ_d
Steel on ice	0.1	0.05
Steel on steel (dry)	0.6	0.4
Steel on steel (greased)	0.1	0.05
Rope on wood	0.5	0.3
Teflon on steel	0.04	0.04
Shoes on ice	0.1	0.05
Climbing boots on rock	1.0	0.8

Large μ → "Sticky"
Small μ → "Slippery"

Static Friction

$\mu_s \times R$ calculates the limit of static friction but below that, it will be equal and opposite to external force



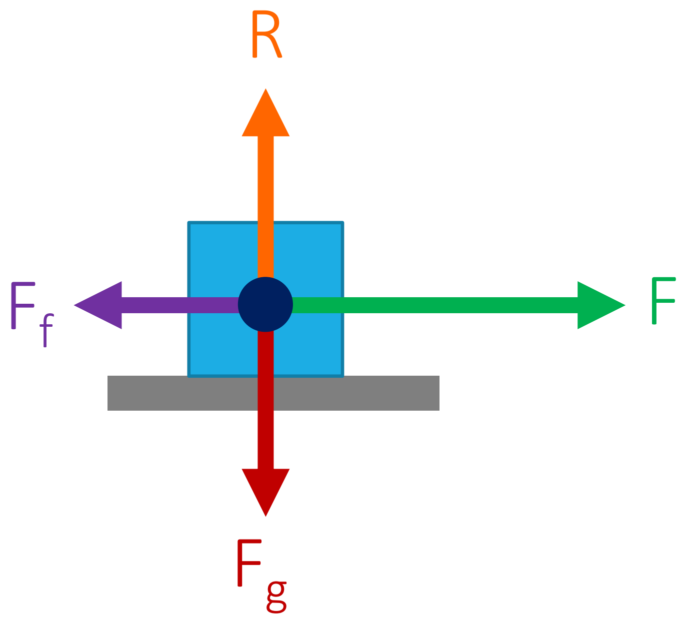
Physics Data Booklet

Sub-topic 2.2 – Forces
$F = ma$ $F_f \leq \mu_s R$ $F_f = \mu_d R$

$F_f = \mu R$

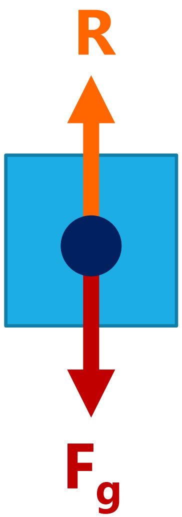
How do we Calculate Friction?

F	External Force
F_g	mg ← $g = 9.81\ m\ s^{-2}$
R	F_g *when flat
F_f	μR



Calculate Friction | Try This…

Santa's Sleigh is loaded up with toys for all the good little girls and boys until it has a total mass of 2000 kg. What is the **static friction** force that must be overcome if μ_s is 0.1?



$$F_g = mg = (2000)(9.81) = 19{,}620 \text{ N}$$

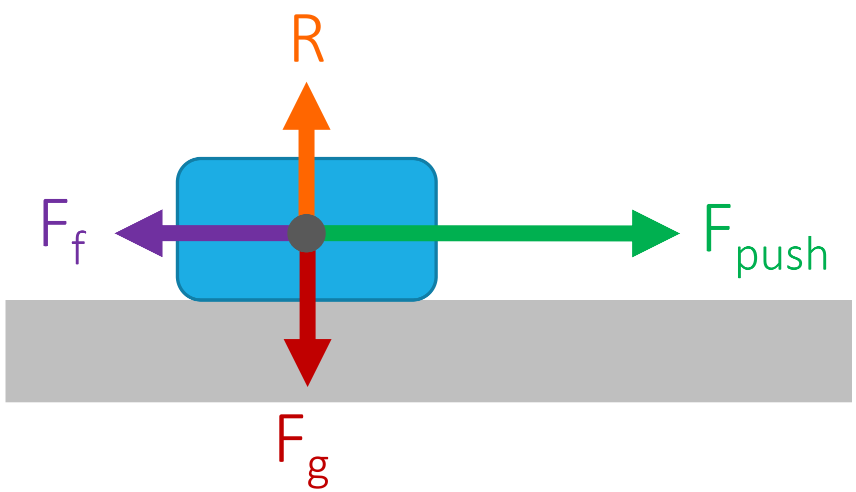
$$R = F_g = 19{,}620 \text{ N}$$

$$F_f = \mu R = (0.1)(19{,}620) = \mathbf{1{,}962\ N}$$

Calculating Acceleration w/ Friction

Step 1:
Find the Force from Friction

- $F_g = mg$
- $R = F_g$
- $F_f = \mu \times R$



Step 2:
Find F_{net}

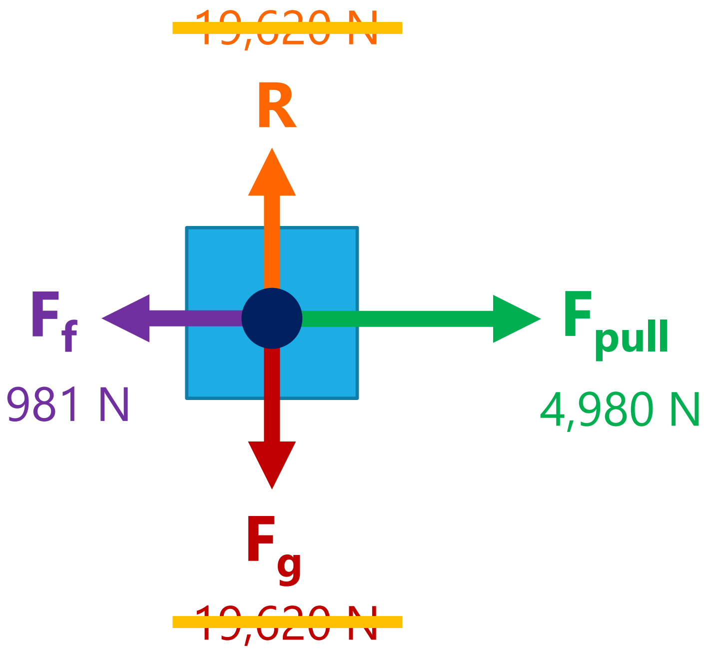
- $F_{net} = F_{push} - F_f$

Step 3:
Find acceleration

$F_{net} = ma$ ➡ $a = F_{net} / m$

Calculate Friction | Try This...

Santa's reindeer pull his 2000 kg sleigh with a force of 4980 N. How fast does the sleigh accelerate if the coefficient of kinetic friction (μ_k) is 0.05?



$F_g = mg = (2000)(9.81) = 19{,}620$ N

$R = F_g = 19{,}620$ N

$F_f = \mu R = (0.05)(19{,}620) = 981$ N

$F_{net} = 4980 - 981 = 3999$ N

$a = F/m = 3999/2000 =$ **$2\ m\ s^{-2}$**

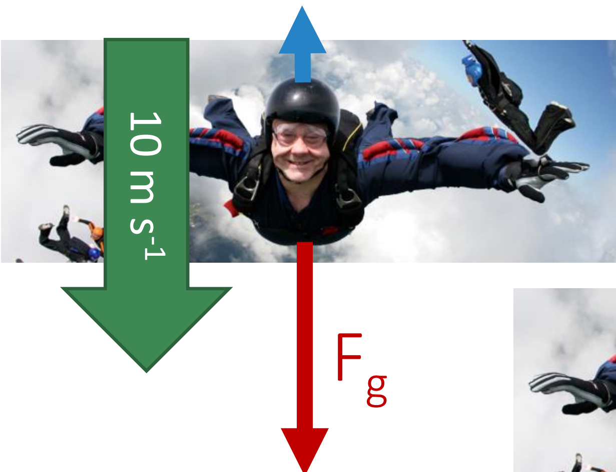
Lesson Takeaways

- ❑ I can calculate the force of friction when given the reaction force and coefficient of friction
- ❑ I can quantitatively compare surfaces based on their coefficients of friction
- ❑ I can calculate the acceleration of an object with friction based on the external force and mass

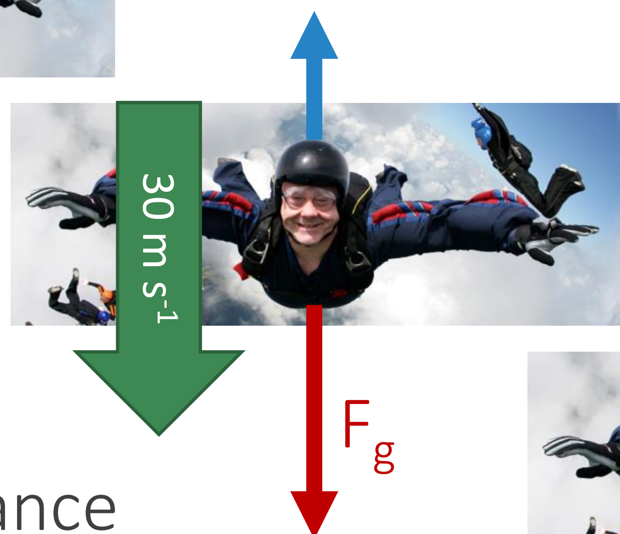
Air Resistance

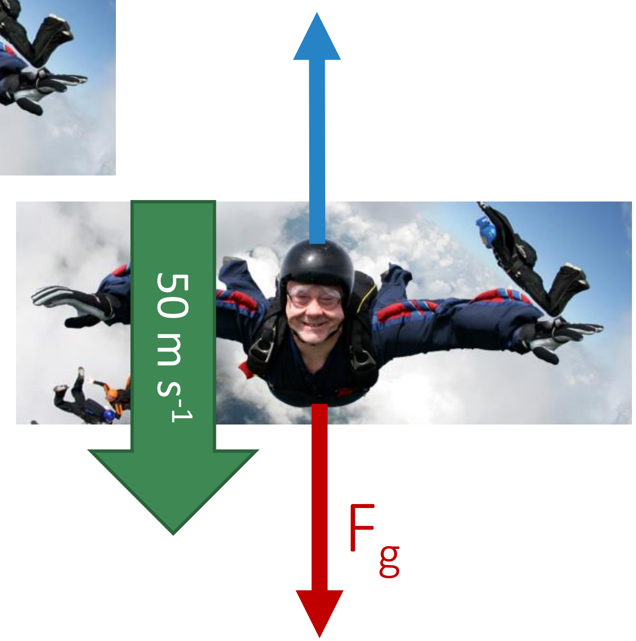
IB PHYSICS | FORCES

Air Resistance



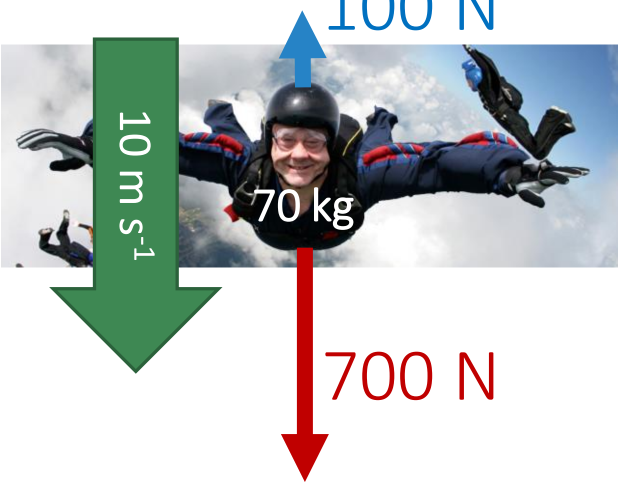
Force of gravity is always _constant_

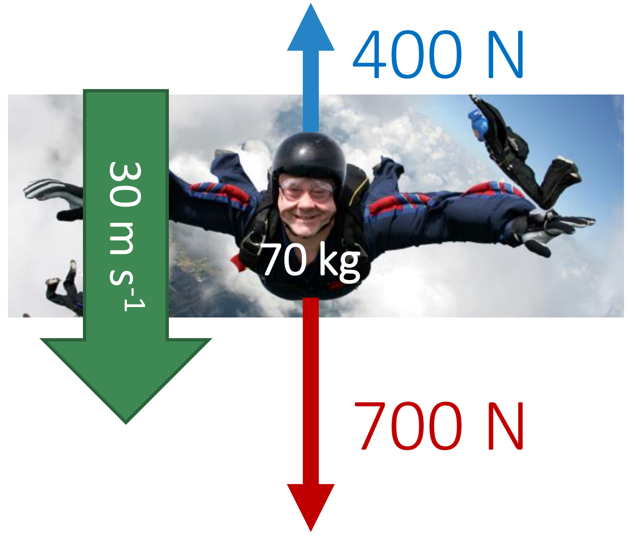


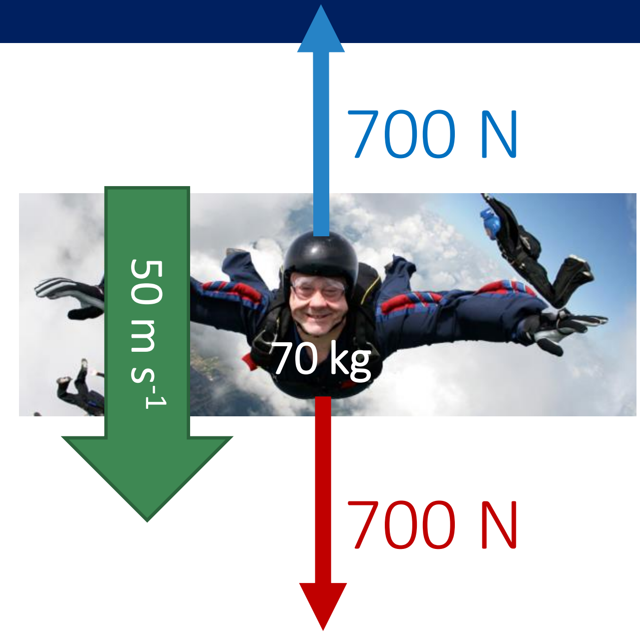


Force of air resistance _increases_ when velocity increases

Calculate the Acceleration







F_{net} = 600 N ↓

$a = \frac{F}{m} = \frac{600}{70} = \mathbf{8.57\ m\ s^{-2}}$

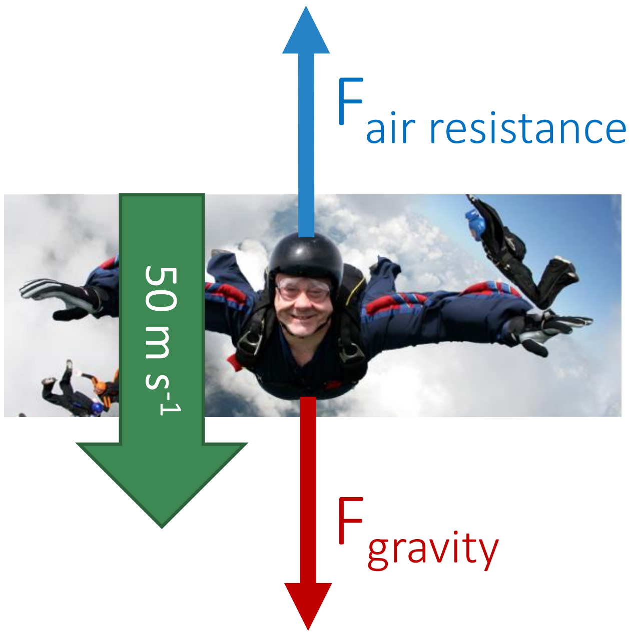
F_{net} = 300 N ↓

$a = \frac{300}{70} = \mathbf{4.29\ m\ s^{-2}}$

F_{net} = 0 N

$a = \frac{0}{70} = \mathbf{0\ m\ s^{-2}}$

Terminal Velocity

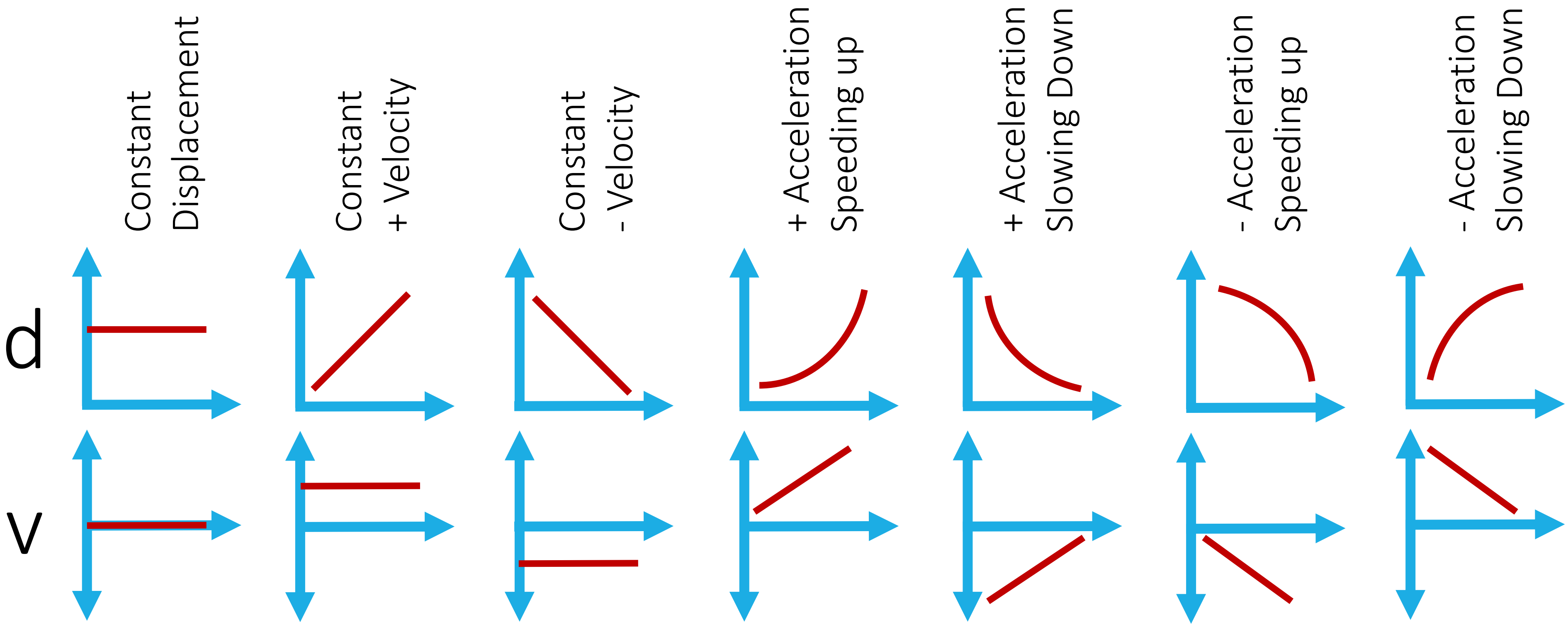


At a certain velocity, the air resistance acting on an object (or person) is equal to the force of gravity.

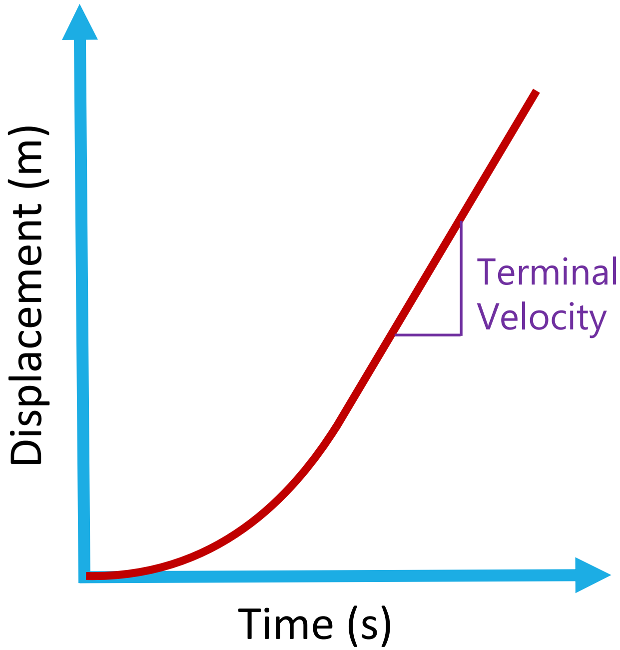
F_{net} = **0 N**

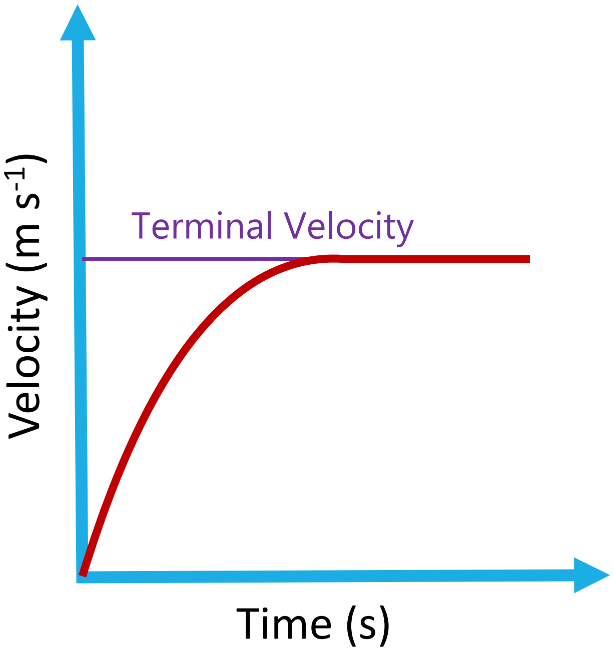
This is the top speed for a falling object

Motion Graphs Guide



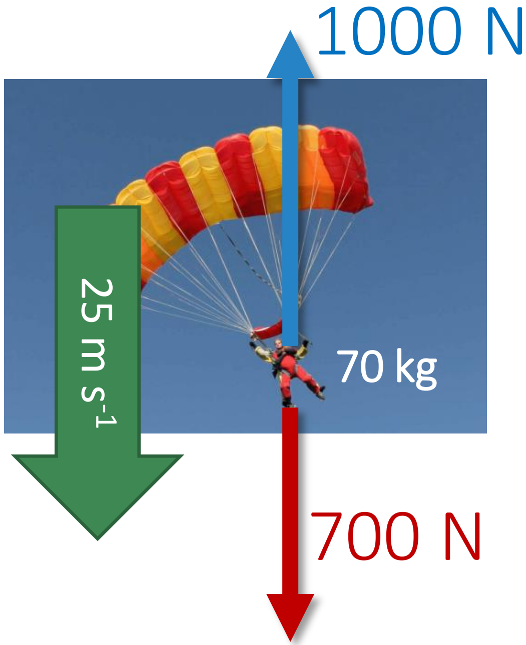
Terminal Velocity





Note: these graphs treat the downward direction as positive

When the Parachute opens…



F_{net} = 500 N ↑

$$a = \frac{F}{m} = \frac{500}{70} = \mathbf{7.14\ m\ s^{-2}}$$

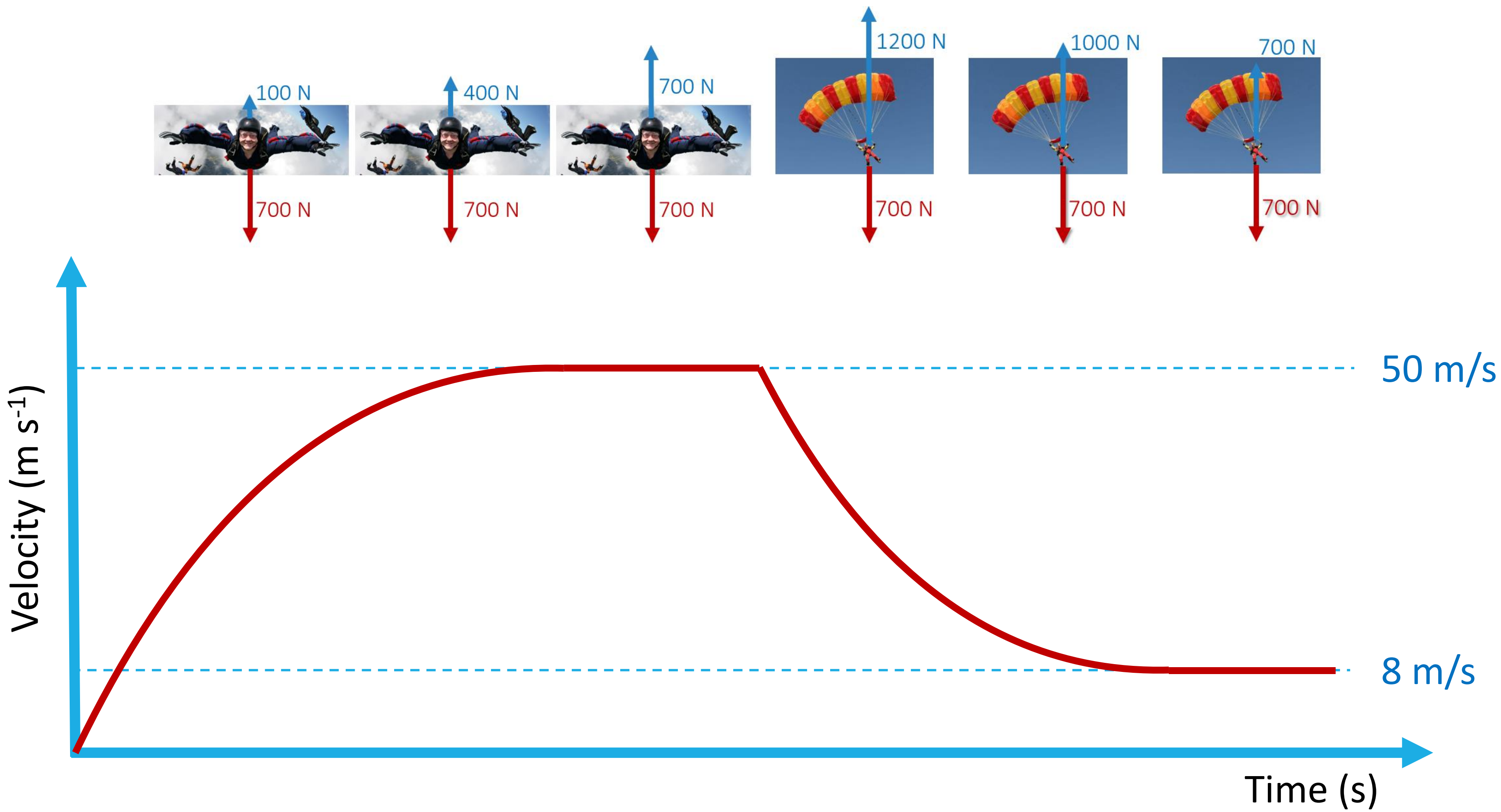
F_{net} = 300 N ↑

$$a = \frac{300}{70} = \mathbf{4.29\ m\ s^{-2}}$$

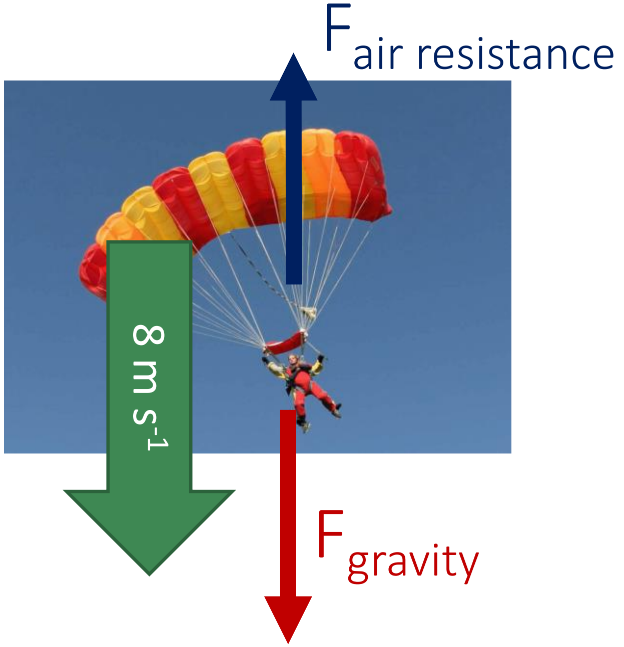
F_{net} = 0 N

$$a = \frac{0}{70} = \mathbf{0\ m\ s^{-2}}$$

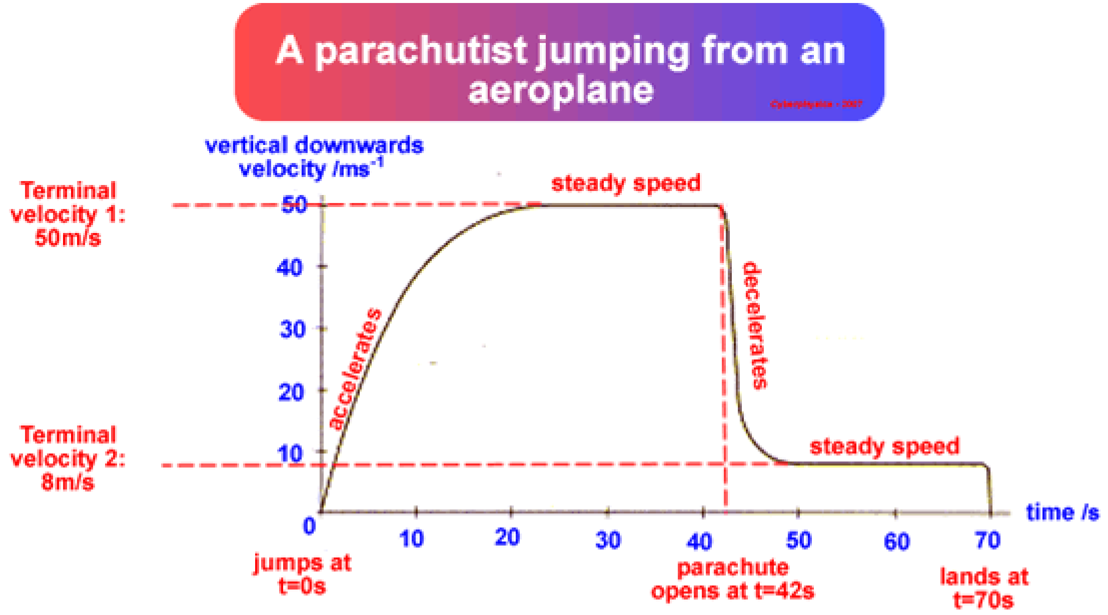
Terminal Velocity



Terminal Velocity



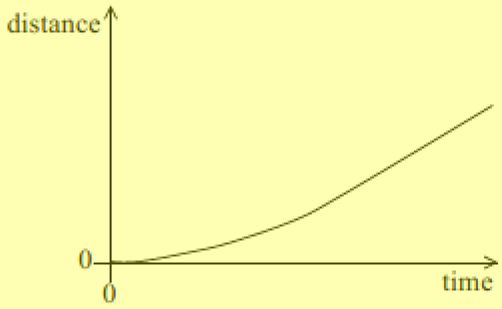
A parachute dramatically decreases the terminal velocity where air resistance balances out the weight



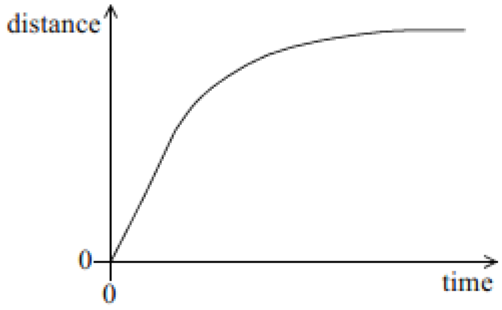
Sample IB Problem

An object falls vertically from rest. Air resistance acts on the object and it reaches a terminal speed. Which of the following is the distance-time graph for its motion?

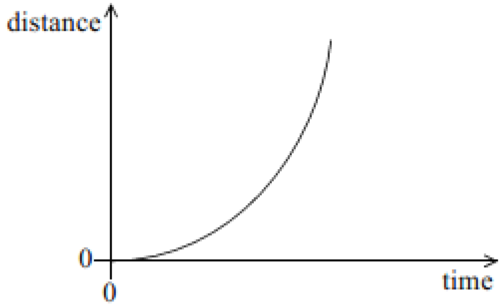
A.



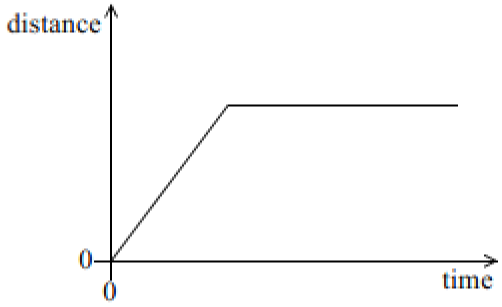
B.



C.



D.



Sample IB Problem

3. A skydiver jumped out of an airplane. On reaching a terminal speed of 60 $m\,s^{-1}$, she opened her parachute. Which of the following describes her motion after opening her parachute?

A. She went upwards for a short time, before falling to Earth at a speed of 60 $m\,s^{-1}$.

B. She continued downwards at 60 $m\,s^{-1}$, but hit the ground with less force.

C. She continued to fall but reached a new terminal speed of less than 60 $m\,s^{-1}$.

D. She went upwards for a short time, before falling to Earth at a speed of less than 60 $m\,s^{-1}$.

Sample IB Problem

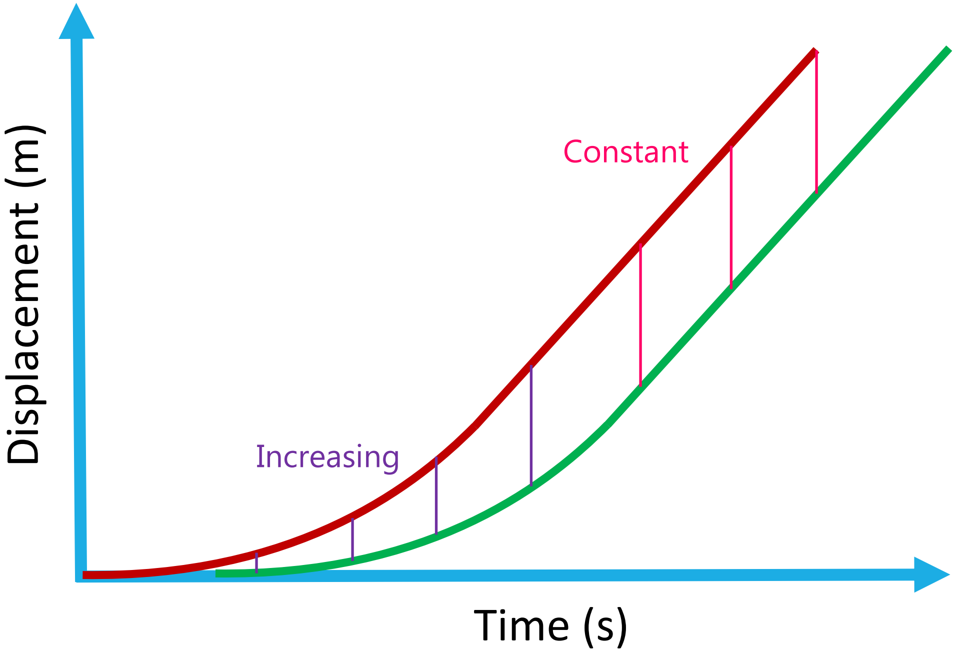
4. Two identical balls are dropped from a tall building, one a few seconds after the other. Air resistance is **not** negligible. As the balls fall, the distance between the balls will

A. decrease.

B. increase.

C. increase then remain constant.

D. remain constant.



Lesson Takeaways

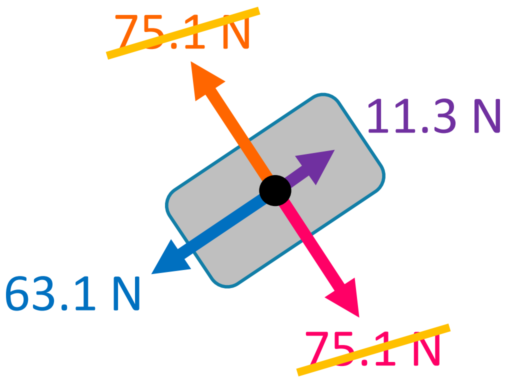
- ❑ I can describe the factors that affect air resistance and how the resistance changes with velocity
- ❑ I can define Terminal Velocity in terms of net force
- ❑ I can graph the change in position and velocity for an object falling with air resistance and reaching terminal velocity

Forces on a Ramp

IB PHYSICS | FORCES

Warm up

What is the acceleration of this 10 kg block?



$F_{net} = 51.8\ \text{N}$

$$a = \frac{F_{net}}{m} = \frac{51.8\ \text{N}}{10\ \text{kg}}$$

$$F_{net} = ma$$

$$a = \mathbf{5.18}\ \boldsymbol{m\ s^{-2}}$$

Big Ideas so Far....

Acceleration is zero when net force is zero

This doesn't mean just mean "stopped" (constant velocity)

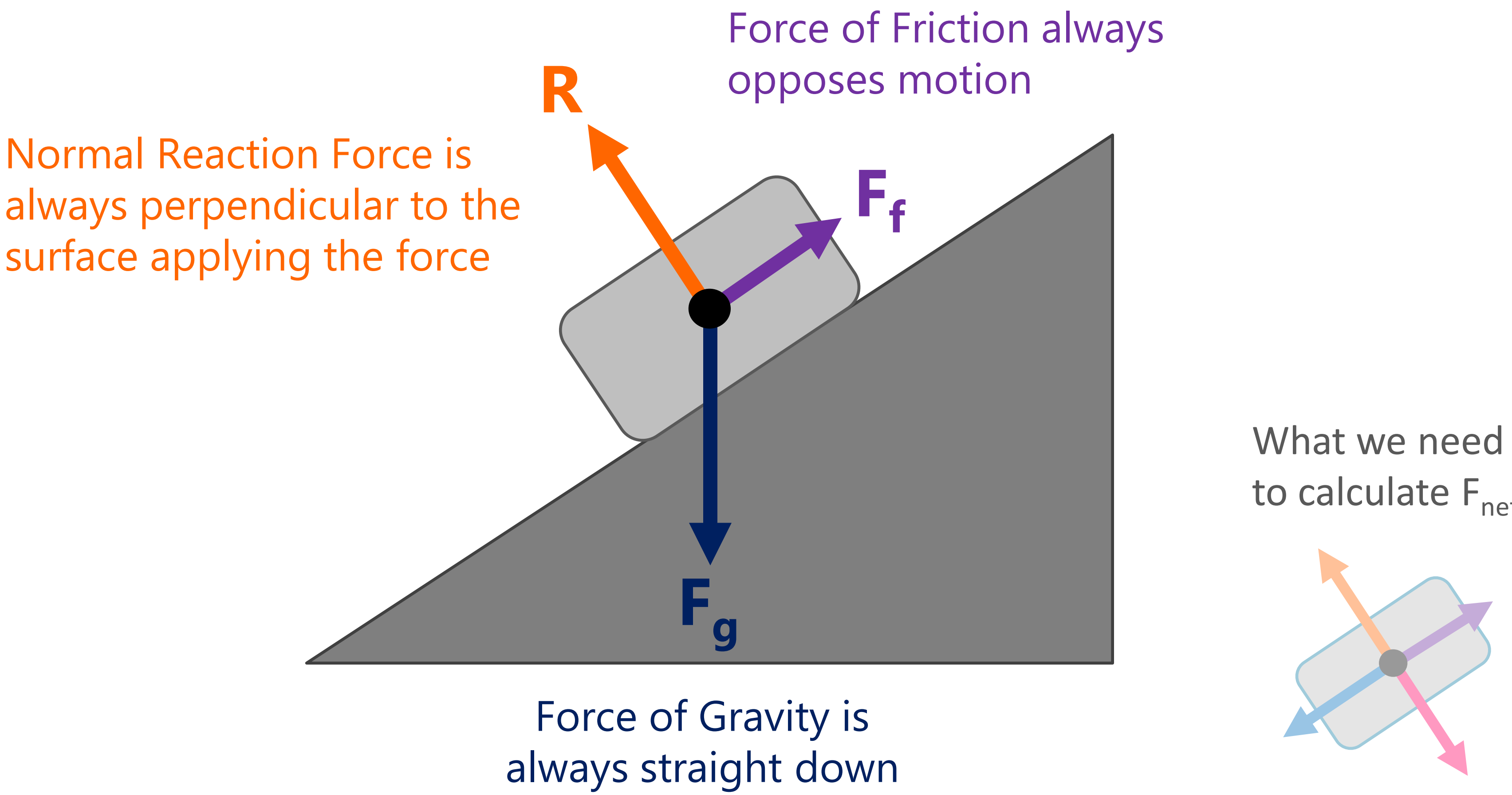
If you have acceleration of an object, you can find the net force causing that acceleration

(Think F = ma)

Force of friction is related to the normal force by the coefficient of friction (μ)

$$F_f = \mu R$$

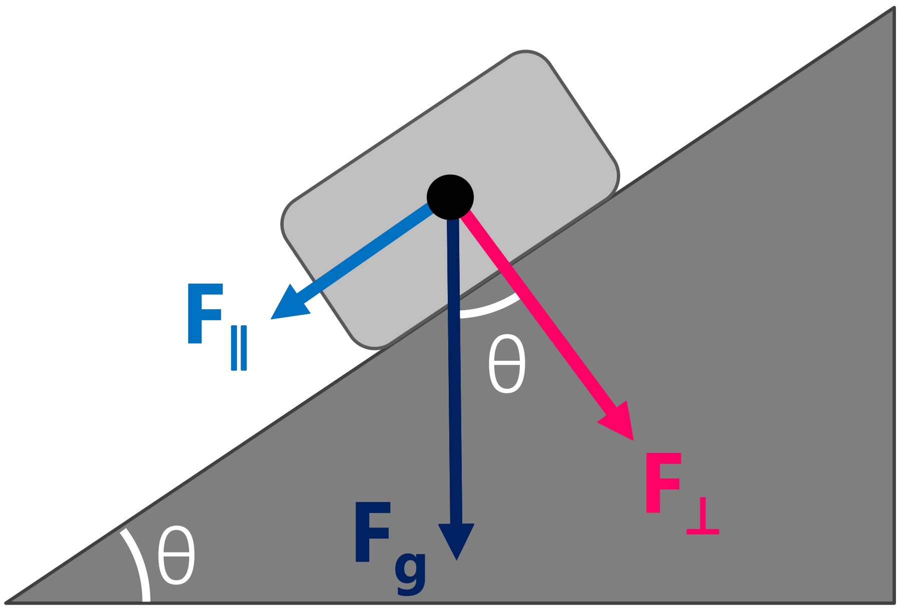
What Forces are acting?



Components of F_g

We try to choose our axes so that we are only looking at forces that are parallel and perpendicular to the motion.

This means that we need to break F_g down into components! ☺

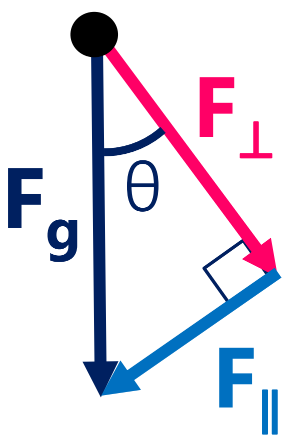


$\sin\theta = F_{\parallel} / F_g$

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

$\cos\theta = F_{\perp} / F_g$

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



Normal and Friction Forces on Ramp

Normal Reaction Force (R)

Force perpendicular to the surface

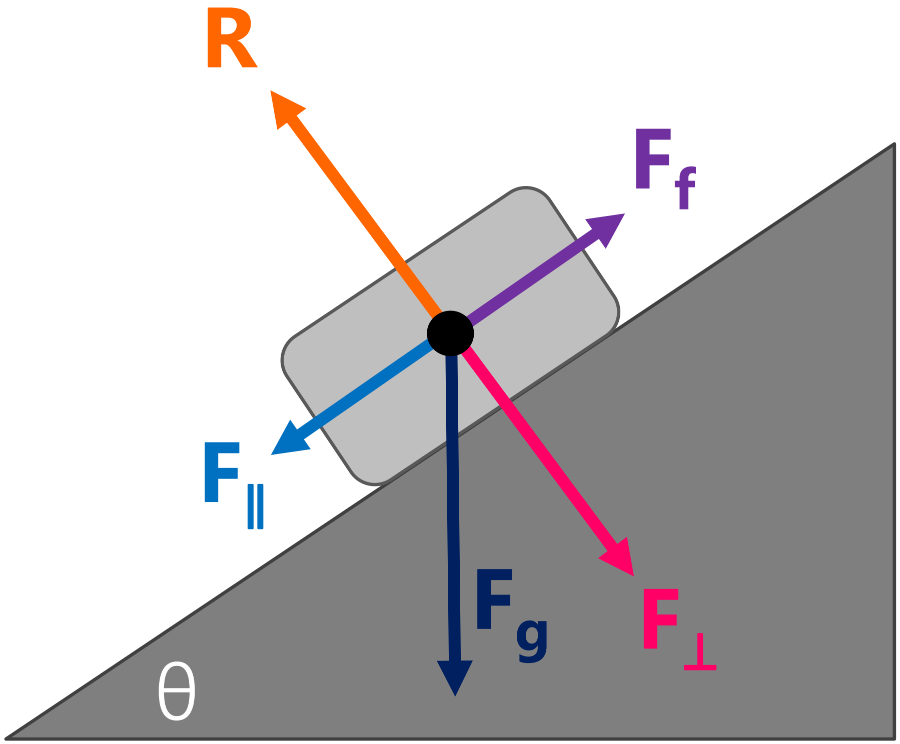
$$R = F_{\perp}$$

Friction Force (F_f)

$$F_f = \mu R$$

*For Equilibrium

$$F_f = F_{\parallel}$$



Example IB Question

A wooden block is sliding down an inclined plane at constant speed. The magnitude of the frictional force between the block and the plane is equal to

A. zero.

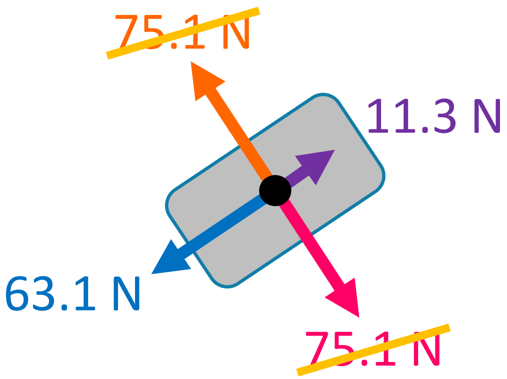
B. the magnitude of the weight of the block.

C. the magnitude of the component of weight of the block parallel to the plane.

D. the magnitude of the component of the normal reaction parallel to the plane.

Warm up

What is the acceleration of this 10 kg block?



F_{net} = 51.8 N

$$a = \frac{F_{net}}{m} = \frac{51.8\text{ N}}{10\text{ kg}}$$

$$F_{net} = ma$$

$$a = \mathbf{5.18\ m\ s^{-2}}$$

Ramp Example

$F_g = mg = (10)(9.81) =$ **98.1 N**

$F_\perp = F_g\cos\theta = 98.1 \times \cos(40) =$ **75.1 N**

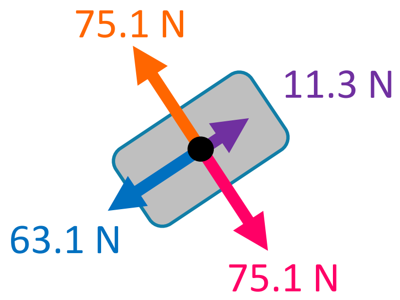
$F_\parallel = F_g\sin\theta = 98.1 \times \sin(40) =$ **63.1 N**

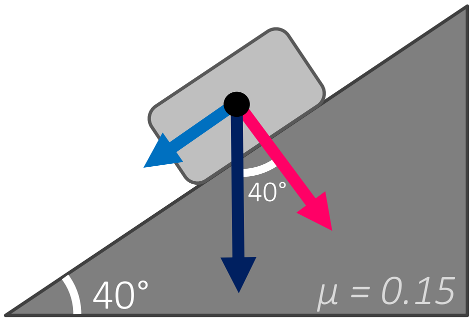
$R = F_\perp =$ **75.1 N**

$F_f = \mu R = (0.15)(75.1) =$ **11.3 N**

$F_{net} = 63.1 - 11.3 =$ **51.8 N**

$a = F/m = 51.8/10 =$ **5.18 m s⁻²**





m	10 kg
F_g	98.1 N
$F_\perp$	75.1 N
$F_\parallel$	63.1 N
R	75.1 N
F_f	11.3 N
F_{net}	51.8 N
a	$5.18\ \text{m s}^{-2}$

What if we didn't know mass?

$F_g = mg$

$F_\perp = F_g\cos\theta = (mg)\cos\theta$

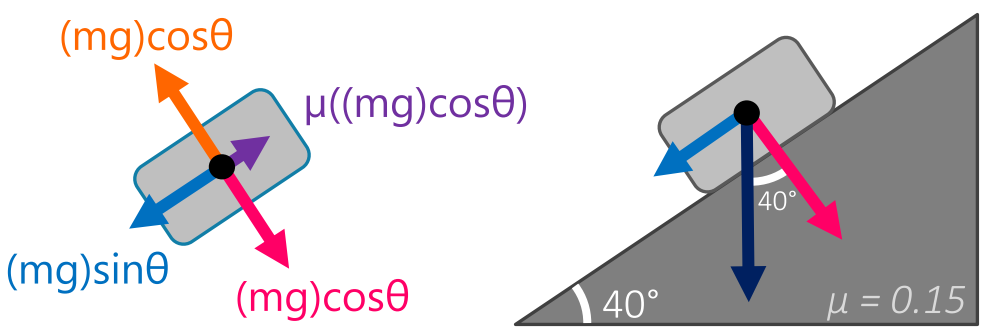
$F_\parallel = F_g\sin\theta = (mg)\sin\theta$

$R = F_\perp = (mg)\cos\theta$

$F_f = \mu R = \mu((mg)\cos\theta)$

$F_{net} = ma = (mg)\sin\theta - \mu((mg)\cos\theta)$

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



For this Example…

$a = (9.81)\sin 40 - 0.15((9.81)\cos 40)$

$a = 6.31 - 1.13$

$a = \mathbf{5.18\ m\ s^{-2}}$