Chapter 4: Forces and Newton's Laws

- Force, mass and Newton's three laws of motion
- Newton's law of gravity
- Normal, friction and tension forces.
- Apparent weight, free fall
- Equilibrium

Force and Mass

Forces have a magnitude and direction – forces are vectors

Types of force –

- Contact – example, a bat hitting a ball
- Noncontact or "action at a distance" – eg, gravitational force

Mass: two types –

- Inertial mass – what is the acceleration when a force is applied?
- Gravitational mass – what gravitational force acts on the mass?

Inertial and gravitational masses are equal

Newton's Laws of Motion

(1) Velocity is constant if a zero net force acts

$$\vec{a} = 0 \text{ if } \vec{F} = 0$$

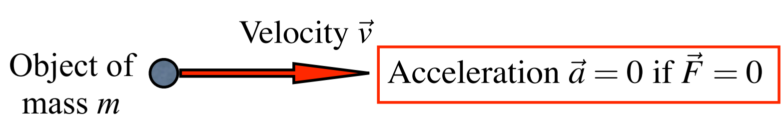
(2) Acceleration is proportional to the net force, inversely proportional to mass:

$$\vec{a} = \vec{F}/m, \quad \text{so } \vec{F} = m\vec{a}$$

The acceleration is in the same direction as the force

(3) Action and reaction forces are equal in magnitude and opposite in direction

Newton's First Law (law of inertia)



The velocity is constant if a zero net force acts on the mass.

That is, if a number of forces act on the mass and their vector sum is zero:

$$\vec{F} = \vec{F}_1 + \vec{F}_2 + \ldots = 0$$

then the acceleration is zero and the mass remains at rest or has constant velocity

Newton's First Law

Was a revolutionary idea that objects continue to move if no force acts:

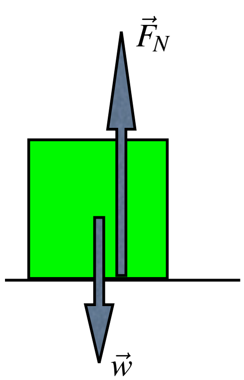
- experience shows that a force is needed to keep objects moving (friction)

- was believed that some cosmic force keeps the planets moving in their orbits

In the absence of friction, objects continue to move at constant velocity if net force is otherwise zero.

If the net force, including the force due to friction, is zero, objects move at constant velocity.

Newton's First Law



A crate is at rest on the ground –

$$\vec{v} = 0,\ \vec{a} = 0$$

What forces act on the crate?

– the weight $\vec{w}$

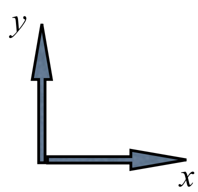
According to Newton's first law, there must be another force so the net force acting on the crate is zero –

–the normal force of the ground acting on the crate, $\vec{F}_N$

$$\vec{F}_N + \vec{w} = 0 \qquad \rightarrow \vec{F}_N = -\vec{w} \quad \text{so crate remains at rest}$$

Inertial Reference Frame

Reference frame – a coordinate system, (*x, y, z*)



Can be defined anywhere –

- right here
- in your car...

An inertial reference frame is one that is **not** accelerated (moves at constant velocity, including zero velocity).

- the law of inertia (first law) applies in an inertial frame – objects at rest remain at rest if no net force acts on them.

- law of inertia does not apply in an accelerated (noninertial) frame.

Example: driving around a corner – velocity changes, force has to be applied *to keep objects from moving*. A noninertial frame.

Newton's Second Law of Motion

Says what happens if the net force acting on a mass is not zero.

The mass accelerates:

Acceleration, $\vec{a} \propto \vec{F}_{net}$ $\quad \vec{F}_{net} =$ net force acting on the mass

proportional to

Introduce the mass:

$$\vec{a} = \frac{\vec{F}_{net}}{m} \qquad \text{or } \vec{F}_{net} = m\vec{a}$$

Units: m in kilograms (kg) $\quad a$ in m/s^2 $\quad F_{net}$ in Newtons (N)

m is the "inertial mass", a measure of how difficult it is to accelerate an object.

Clickers!

All of the following, except one, cause the acceleration of an object to double. Which one is it?

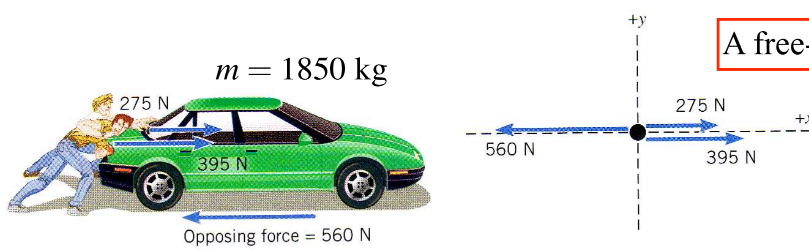
A) All forces acting on the object double

B) The net force acting on the object doubles

C) Both the net force acting on the object and the mass of the object double

D) The mass of the object is reduced by a factor of two

Newton's Second Law of Motion



(a) (b) Free-body diagram of the car

A free-body diagram

Shows only the forces acting on the car

Two people push a car against an opposing force of 560 N.

One exerts 275 N, the other 395 N of force on the car.

$$F_{net} = 275 + 395 - 560 \text{ N} = 110 \text{ N, to the right}$$

$$\text{Acceleration, } a = F_{net}/m = (110 \text{ N})/(1850 \text{ kg}) = \underline{0.059 \text{ m/s}^2}$$

Newton's Second Law of Motion

A catapult on an aircraft carrier accelerates a 13,300 kg plane from 0 to 56 m/s in 80 m. Find the net force acting on the plane.

$F_{net} = ma$ (acceleration along a straight line)

What is a?

$v^2 = v_0^2 + 2ax$

or, $56^2 = 0 + 2a \times 80$

So, $a = 56^2/160 = 19.6\ \text{m/s}^2$

Therefore, $F_{net} = (13,300\ \text{kg}) \times (19.6\ \text{m/s}^2) = 261,000\ \text{N}$

Mastering Physics Assignment 1

Deadline has been extended to October 1 because of difficulty with configuration of open-area computers on campus
(Flash, javascript errors - being fixed)
Try Firefox if no luck!

Mastering Physics Assignment 2

Is available on Mastering Physics website
Seven practice problems + six for credit
Due Wednesday, October 10 at 11 pm

Newton's Laws of Motion

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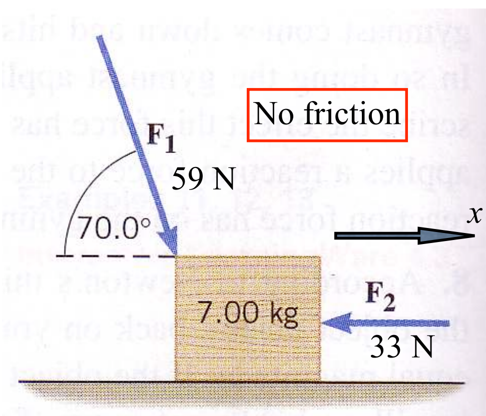
$$\vec{a} = \vec{F}/m, \quad \text{so } \vec{F} = m\vec{a}$$

The acceleration is in the same direction as the force

(3) Action and reaction forces are equal in magnitude and opposite in direction

Newton's Second Law



4.11: What is the acceleration of the block in the horizontal direction?

Work out the components of forces in the x-direction.

$$F_x = F_{1x} + F_{2x}$$

$$= F_1 \cos 70^\circ - F_2 = -12.8 \text{ N}$$

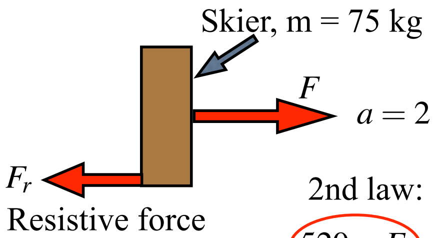
As $\vec{a} = \vec{F}/m$ then, $a_x = F_x/m = (-12.8 \text{ N})/(7 \text{ kg})$

$$= -1.83 \text{ m/s}^2$$

Newton's Second Law

4.-/88: A 75 kg water skier is pulled by a horizontal force of 520 N and has an acceleration of 2.4 m/s^2.

Assuming the resistive force from water and wind is constant, what force would be needed to pull the skier at constant velocity?



$a = 2.4\ \text{m/s}^2$ when $F = 520\ \text{N}$

2nd law: $F_{net} = ma$ (in horizontal direction)

$520 - F_r = 75 \times 2.4 = 180\ \text{N}$ So, $F_r = 340\ \text{N}$

If the pulling force is reduced to 340 N, the net force acting on the skier will be zero and his/her speed will be constant.

Newton's Second Law

4.-/4: A special gun is used to launch objects into orbit around the earth.

It accelerates a 5 kg projectile to 4 × 10^3 m/s by applying a net force of 4.9 × 10^5 N.

How much time is needed to accelerate the projectile?

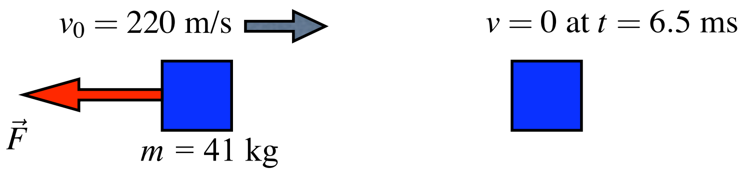
$$F = ma = m\Delta v/\Delta t$$

$$\text{So } \Delta t = m\Delta v/F = \frac{(5\ \text{kg}) \times (4 \times 10^3\ \text{m/s})}{4.9 \times 10^5\ \text{N}}$$

$$= 0.0408\ \text{s} = 41\ \text{ms}$$

Newton's Second Law

4.14: A 41 kg box is thrown at 220 m/s against a barrier. It is brought to a halt in 6.5 ms. What is the average net force that acts on the box?



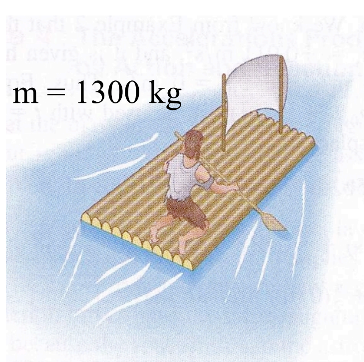
$F = ma$, but what is a?

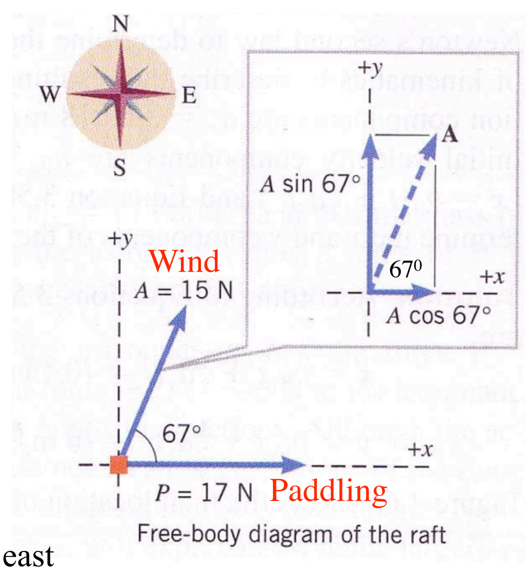
$v = v_0 + at$

$0 = (220 \text{ m/s}) + a \times (0.0065 \text{ s}) \rightarrow a = -220/0.0065 = -33,850 \text{ m/s}^2$

Then, $F = (41 \text{ kg}) \times (-33,850 \text{ m/s}^2) = -1.39 \times 10^6$ N

Newton's Second Law



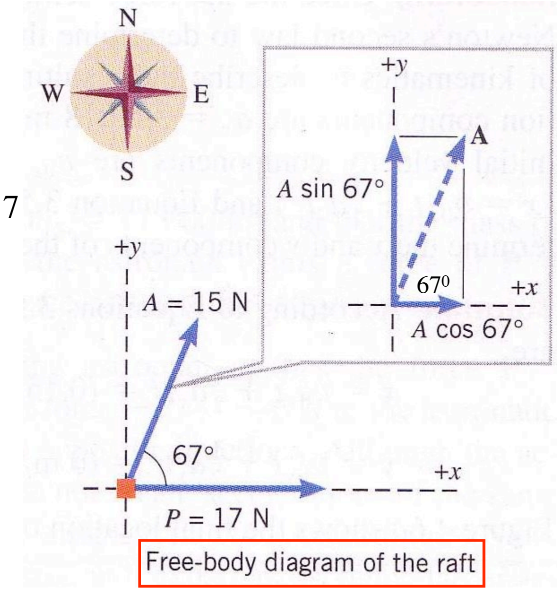


Paddling: force **P** of 17 N, to east
Wind: force **A** of 15 N, 67° north of east

Find a_x, a_y for the raft.

Net force is $\vec{F} = \vec{A} + \vec{P}$

Net force is $\vec{F} = \vec{A} + \vec{P}$



So $F_x = A_x + P_x = 15\cos 67^\circ + 17$

$F_y = A_y + P_y = 15\sin 67^\circ$

Then, $a_x = F_x/m$

$a_y = F_y/m$

$$a_x = \frac{(22.9\text{ N})}{(1300\text{ kg})} = 0.018\text{ m/s}^2$$

$$a_y = \frac{(13.8\text{ N})}{(1300\text{ kg})} = 0.011\text{ m/s}^2$$

Total acceleration: $a = \sqrt{a_x^2 + a_y^2} = 0.021\text{ m/s}^2$

$$\tan\theta = \frac{a_y}{a_x} \rightarrow \theta = 31^\circ\text{, N of E}$$

Newton's Second Law

4.17: A 325 kg sailboat is sailing 15.0^0 north of east at 2.00 m/s. 30 s later, it is sailing 35^0 north of east at 4.00 m/s.

Three forces act on the boat:

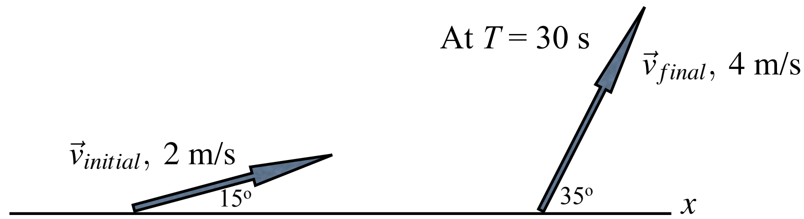
- 31 N at 15° north of east $= \vec{F}_1$
- 23 N at 15° south of west $= \vec{F}_2$
- $\vec{F}_w$, due to the wind $= \vec{F}_w$

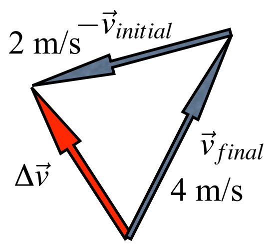
$$\vec{F}_1 + \vec{F}_2 + \vec{F}_w = m\vec{a}$$

Solve by working out the average acceleration, then calculate the missing force, F_w.

31 N at 15^0 north of east, 23 N at 15^0 south of west

$$\text{Average acceleration, } \vec{a} = \frac{\vec{v}_{final} - \vec{v}_{initial}}{T} = \frac{\vec{v}_{final} + (-\vec{v}_{initial})}{T} = \frac{\Delta\vec{v}}{T}$$





$$\Delta v_x = 4\cos 35^\circ - 2\cos 15^\circ = +1.345 \text{ m/s}$$

$$\Delta v_y = 4\sin 35^\circ - 2\sin 15^\circ = +1.777 \text{ m/s}$$

$$a_x = (1.345 \text{ m/s})/(30 \text{ s}) = +0.0448 \text{ m/s}^2$$

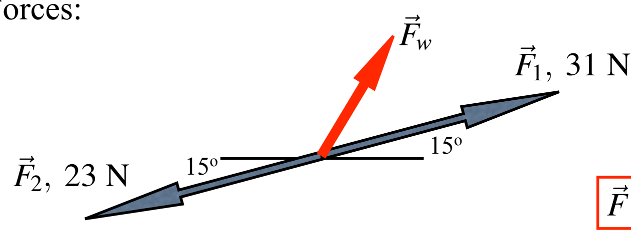
$$a_y = (1.777 \text{ m/s})/(30 \text{ s}) = +0.0592 \text{ m/s}^2$$

$$a_x = +0.0448 \text{ m/s}^2, \ a_y = +0.0592 \text{ m/s}^2$$

So, $F_x = ma_x = (325 \text{ kg}) \times (0.0448 \text{ m/s}^2) = 14.56 \text{ N}$

$F_y = ma_y = (325 \text{ kg}) \times (0.0592 \text{ m/s}^2) = 19.24 \text{ N}$

Forces:

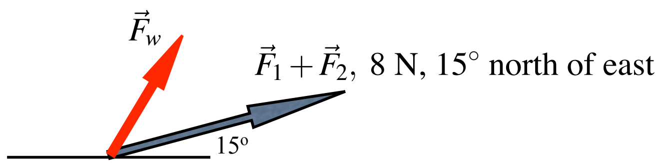


$$\vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_w$$

Simplification: $\vec{F}_2$ is directly opposite $\vec{F}_1$

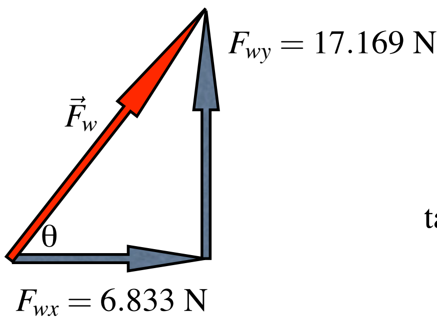
So, $\vec{F}_1 + \vec{F}_2 = 31 - 23 = 8$ N at 15° north of east

$F_x = 14.56$ N, $F_y = 19.24$ N



$$F_x = (8\text{ N}) \times \cos 15^\circ + F_{wx} = 14.56\text{ N} \;\rightarrow F_{wx} = 6.833\text{ N}$$

$$F_y = (8\text{ N}) \times \sin 15^\circ + F_{wy} = 19.24\text{ N} \;\rightarrow F_{wy} = 17.169\text{ N}$$



$$F_w = \sqrt{F_{wx}^2 + F_{wy}^2} = 18.5\text{ N}$$

$$\tan\theta = 17.169/6.833$$

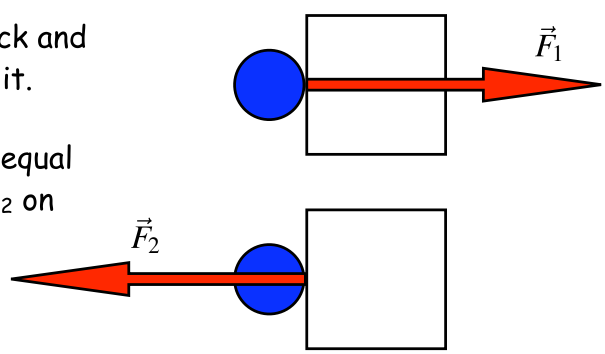
$$\rightarrow \theta = 68.3^\circ \text{ north of east}$$

Newton's Third Law of Motion

When you exert a force on an object, it exerts a force back on you (otherwise you fall over).

The ball hits the block and exerts a force F_1 on it.

The block exerts an equal and opposite force F_2 on the ball.

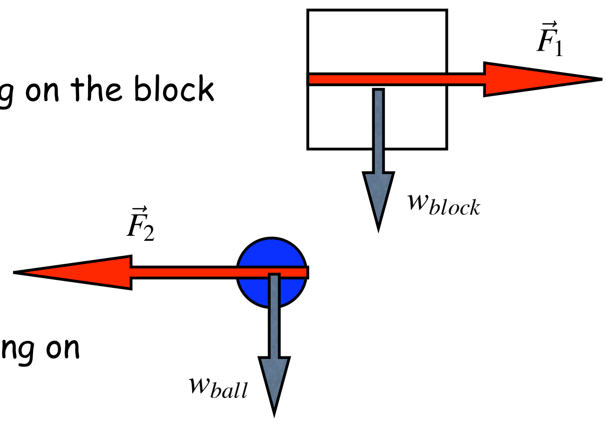


$$\vec{F}_2 = -\vec{F}_1$$

That is, action and reaction forces are equal and opposite

Action and reaction forces act on **DIFFERENT OBJECTS**!

All of the forces acting on the block



All of the forces acting on the ball

As action and reaction forces act on **different** objects, **the forces do not cancel**.

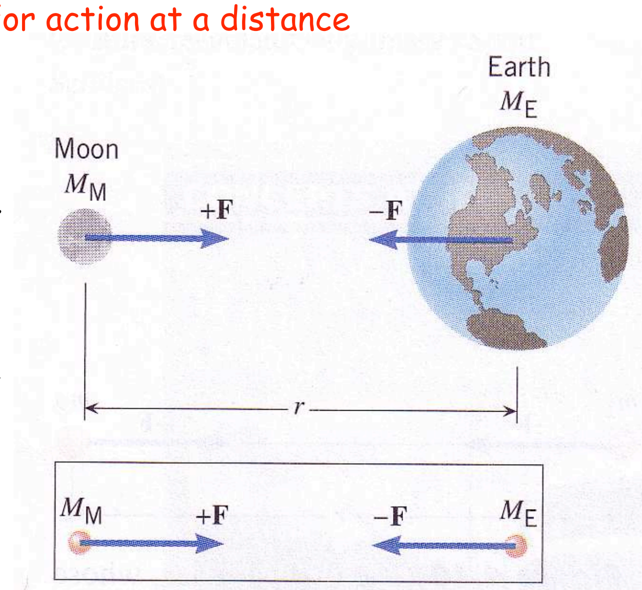
Action and Reaction Forces

- also for action at a distance

The earth exerts a gravitational force on the moon.

The moon exerts an equal and opposite force on the earth.

Implies that the force is proportional to the product of the masses:-



$$F \propto M_M M_E$$

Mastering Physics Assignment 1

Deadline is October 1 at 5 pm
Flash problem believed to be fixed as of Friday
Try Firefox if still a problem!

Mastering Physics Assignment 2

Is available on Mastering Physics website
Seven practice problems + six for credit
Due Wednesday, October 10 at 11 pm

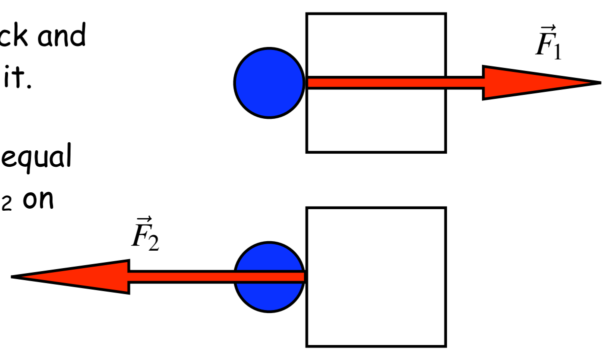
Newton's Third Law of Motion

When you exert a force on an object, it exerts a force back on you.

The ball hits the block and exerts a force F_1 on it.

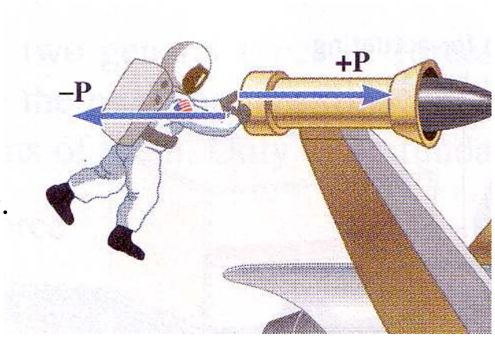
The block exerts an equal and opposite force F_2 on the ball.

$$\vec{F}_2 = -\vec{F}_1$$



Action and reaction forces are equal and opposite, and **they act on different objects**

Newton's Third Law of Motion



An astronaut of mass m_a = 92 kg exerts a force P = 36 N on a spacecraft of mass m_s = 11,000 kg.

What is the acceleration of each?

Force on the spacecraft, P = 36 N to the right.
Second Law:
Acceleration of craft, $a_s = P/m_s$ = (36 N)/(11,000 kg) = 0.0033 m/s^2

Reaction force of spacecraft on the astronaut is –P (Newton's 3rd law).
Second Law:
Acceleration of astronaut, $a_a = -P/m_a$ = (–36 N)/(92 kg) = –0.39 m/s^2

The Fundamental Forces of Nature

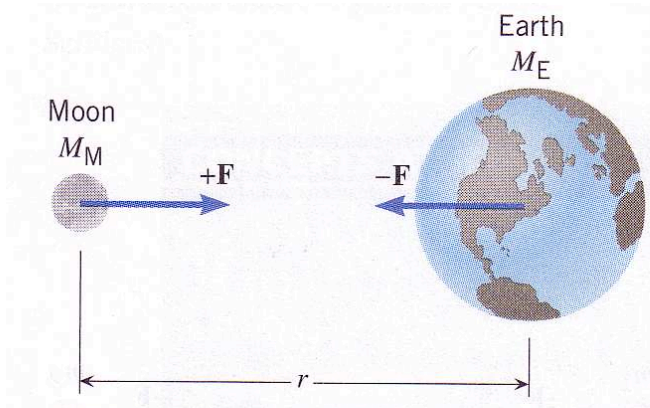
- **Strong Nuclear Force**: the strongest of all. Responsible for holding neutrons and protons captive in the nuclei of atoms. Acts over only very short distances of about 10^{-15} m.

- **Electroweak Force**: a combination of:

  – **electromagnetic force**: binds electrons to nuclei to form atoms and molecules.
  – **weak nuclear force**: responsible for nuclear beta-decay.

- **Gravity**: the weakest force of all. A significant force because all matter (we believe) is attracted by gravity.

- **Perhaps**, a repulsive gravitational force acting at long distances (distant galaxies appear to be moving away faster than they should if only normal gravity acts).



The earth exerts a gravitational force on the moon that is proportional to M_M.

The moon exerts a gravitational force on the earth that is proportional to M_E.

→ As the forces are equal in magnitude (3rd law), the gravitational force must depend on both M_M and M_E.

Newton's Law of Gravitation

(deduced from observations of the motion of the planets)

The gravitational force between two masses, m_1 and m_2, is proportional to the product of the masses and inversely proportional to the square of the distance between their centres.

$$F_{grav} = \frac{Gm_1m_2}{r^2}$$

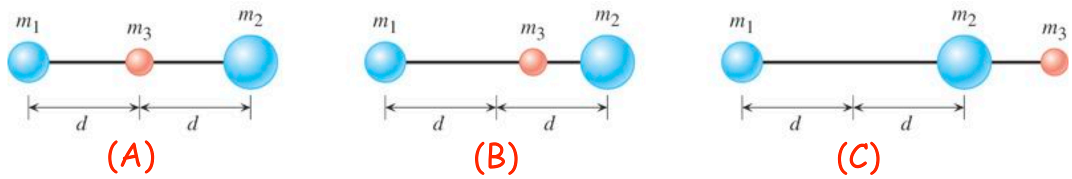
Distance between centres of gravity

G is the universal gravitational constant:

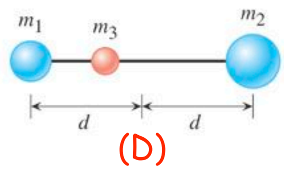
$$G = 6.673 \times 10^{-11}\ \mathrm{N.m^2/kg^2}$$

m_1, m_2 are "gravitational masses". In all cases seen, they are equal to the inertial masses (the mass in F = ma).

Clickers!



m_2 > m_1

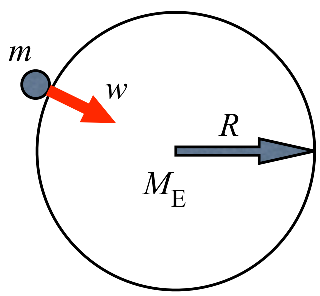


Three objects of mass m_1, m_2, m_3 are located along a straight line. m_2 is greater then m_1. The net gravitational force acting on mass m_3 is zero.

Which drawing correctly represents the locations of the objects?

Gravity attracts m_3 toward both m_1 and m_2, and F ~ $1/r^2$

Newton's Law of Gravitation



Earth:
$M_E = 5.98 \times 10^{24}$ kg
$R = 6.38 \times 10^6$ m

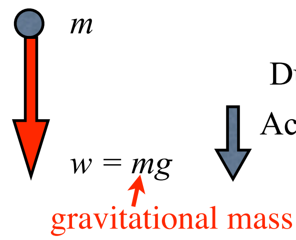
What is the gravitational force (weight, w) of a mass m on the earth's surface?

$$w = \frac{GmM_E}{R^2} = (6.673 \times 10^{-11}\ \mathrm{N.m^2/kg^2}) \times \frac{m \times (5.98 \times 10^{24}\ \mathrm{kg})}{(6.38 \times 10^6\ \mathrm{m})^2}$$

$$w = 9.80 \times m = mg \qquad g = \frac{GM_E}{R^2} \text{ at earth's surface}$$

Above earth's surface, weight decreases with distance r from the centre of the earth as $1/r^2$.

Weight and Gravitational Acceleration



Due to gravity –

Acceleration = a, downwards

Newton's second law: $w = ma$ (w accelerates the mass)

So weight, $w = mg = ma$

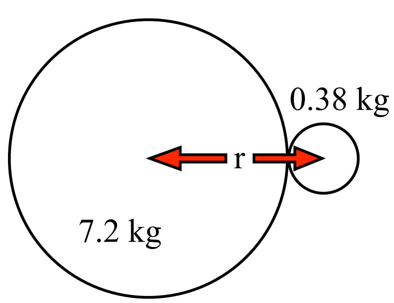
inertial mass

and $a = g$ independent of mass.

All objects fall equally fast in the absence of air resistance

If gravitational and inertial masses were not equal, this would not be the case!

4.19/18: A bowling ball (mass m_1 = 7.2 kg, radius r_1 = 0.11 m) and a billiard ball (mass m_2 = 0.38 kg, radius r_2 = 0.028 m) may be treated as uniform spheres. What is the magnitude of the maximum gravitational force between them?



Gravitational force between them:

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

Distance between centres:

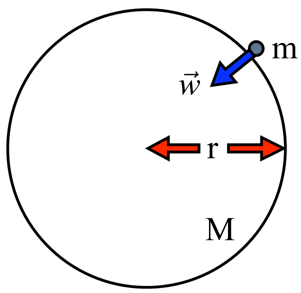
$$r = r_1 + r_2 = 0.11 + 0.028 = 0.138 \text{ m}$$

$$F = (6.673 \times 10^{-11} \text{ N.m}^2/\text{kg}^2) \times \frac{(7.2 \text{ kg}) \times (0.38 \text{ kg})}{(0.138 \text{ m})^2}$$

$$= 9.6 \times 10^{-9} \text{ N}$$

Newton's Law of Gravitation

4.-/26: The weight of an object is the same on planets A and B. The mass of planet A is 60% that of planet B. Find the ratio of the radii of the planets.



Weight of mass m on the surface of a planet of radius r and mass M:

$$w = G\frac{mM}{r^2}$$

On planet A: $w_A = G\frac{mM_A}{r_A^2}$

On planet B: $w_B = G\frac{mM_B}{r_B^2}$

The weights are the same, so: $G\frac{mM_A}{r_A^2} = G\frac{mM_B}{r_B^2}$

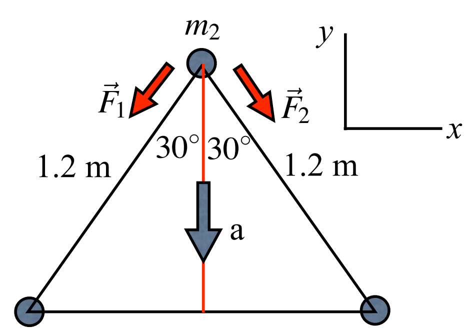
$$\text{So } \frac{r_A}{r_B} = \sqrt{\frac{M_A}{M_B}} = \sqrt{0.6} = 0.775$$

Newton's Law of Gravitation

4.28: Three uniform spheres are located at the corners of an equilateral triangle with sides of 1.2 m.

Two of the spheres have a mass of 2.8 kg. The third sphere is released from rest.

What is the magnitude of its initial acceleration?



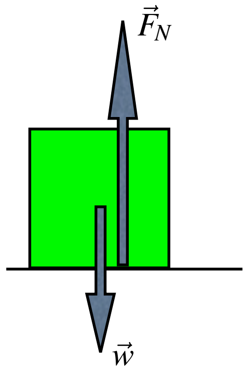
$m_1 = 2.8$ kg $\quad m_1 = 2.8$ kg

$$F_1 = F_2 = G\,\frac{m_2 \times (2.8 \text{ kg})}{(1.2 \text{ m})^2} \qquad F_{1x} + F_{2x} = 0 \text{ (symmetry)}$$

$$F_{1y} + F_{2y} = -2F_1 \cos 30^\circ = -2.247 \times 10^{-10} \times m_2$$

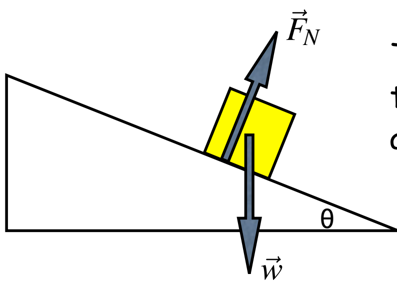
$$\text{Acceleration } = \frac{-2.247 \times 10^{-10} \times m_2}{m_2} = -2.247 \times 10^{-10} \text{ m/s}^2$$

The Normal Force



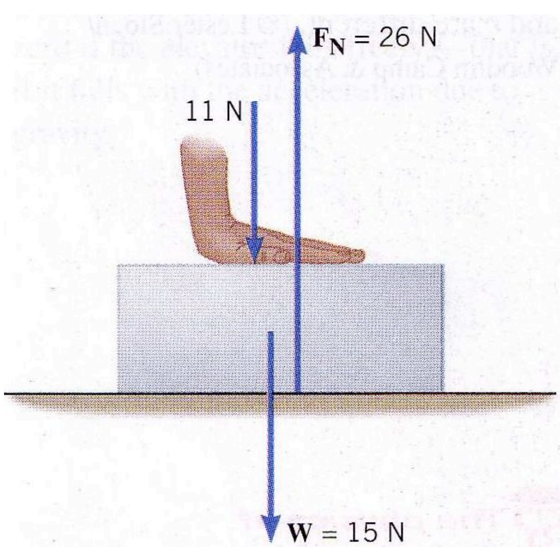
The normal force acts when an object is in contact with a surface and exerts a force on it.

The normal force is perpendicular (normal) to the surface.



The normal force acts no matter what the angle of the surface is and is always perpendicular to the surface.

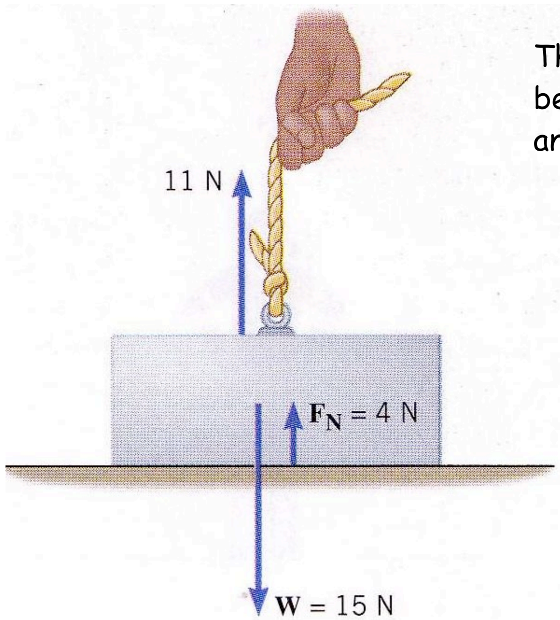
The Normal Force



The normal force $\mathbf{F_N}$ of the ground on the block supports all of the forces pushing down on the ground:

$$F_N = 15 + 11 = 26 \text{ N}$$

The Normal Force

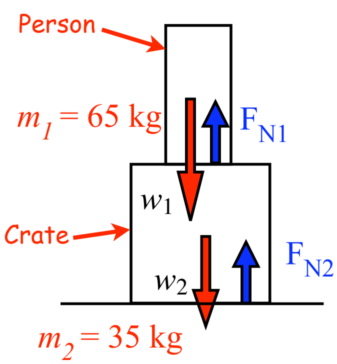


The normal force is reduced because the rope is exerting an upward force on the block:

$$F_N = 15 - 11 = 4 \text{ N}$$

The normal force also changes if there is acceleration upward or downward.

The Normal Force



4.34: A 65 kg person stands on a 35 kg crate.

Normal force F_{N2} supports both masses:

$$F_{N2} = (65 + 35)g = 980 \text{ N}$$

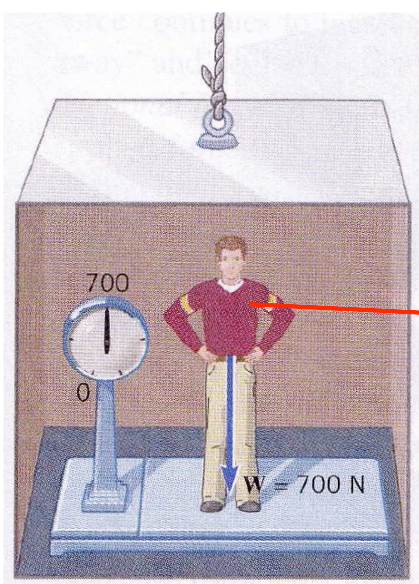
Normal force F_{N1} supports only the person:

$$F_{N1} = 65g = 637 \text{ N}$$

To do –

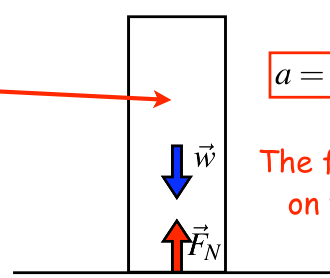
- The bathroom scales in the elevator problem - how did they get there?
- Apparent weight
- Free fall
- Friction, static and kinetic
- Equilibrium
- Non-equilibrium

Apparent Weight



$w = mg = 700$ N

The scale shows the force needed to support the person – it is the normal force, F_N of the scale on the feet of the person.



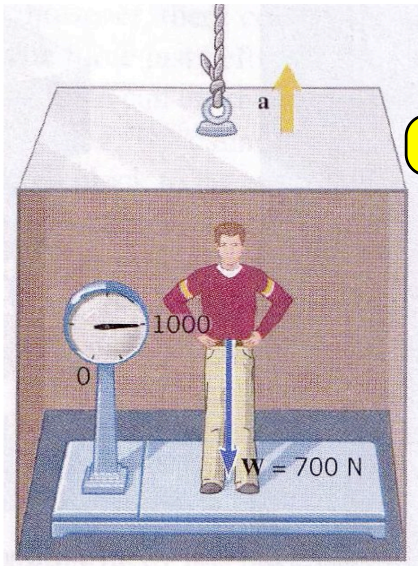
$a = 0,\ \vec{v}$ constant

The forces acting on the person

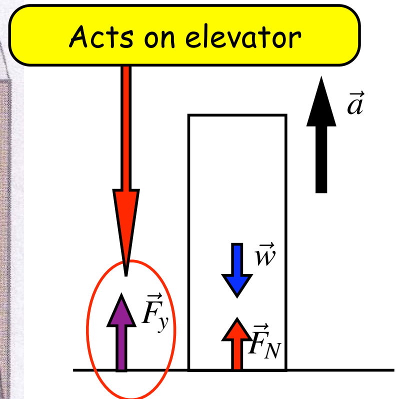
$$\vec{F}_N + \vec{w} = 0$$

$F_N = 700$ N = weight of person, mg

Apparent Weight



A force is accelerating the elevator upward at rate a.

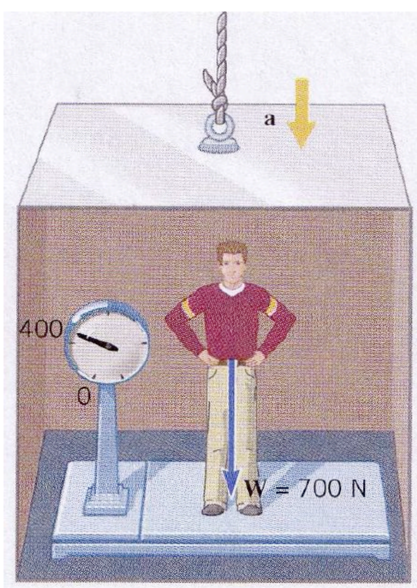


Magnitudes of forces acting on person:

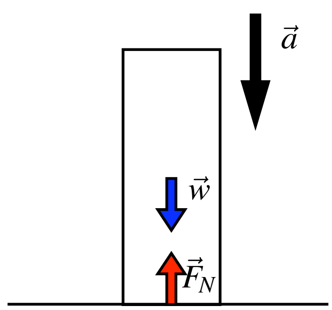
$$F_{net} = F_N - w = ma \quad \text{(2nd law)}$$

Or, apparent weight, $F_N = w + ma \; = 1000 \text{ N}$

Apparent Weight



The elevator is accelerated downward.

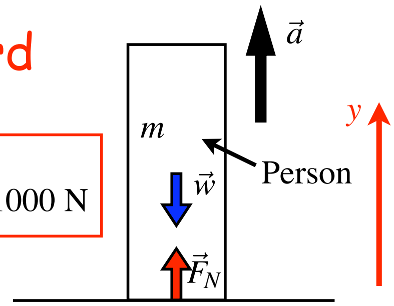


Net **downward** force acting on the person:

$$F_{net} = w - F_N = ma$$

So apparent weight is: $F_N = w - ma \; = 400 \text{ N}$

Elevator accelerating upward



Weight of person, w = 700 N
Apparent weight = weight read by scales, F_N = 1000 N

Net force on person in the upward direction:

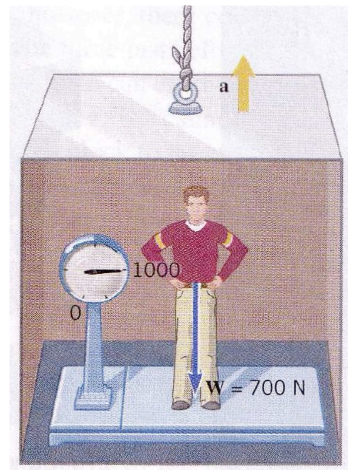
$F_N - w = ma$ (Newton's 2nd law)

So, $a = (F_N - w)/m$

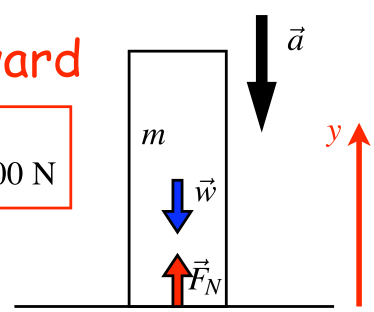
As $w = mg$, or $m = w/g$

$a = (F_N - w)g/w = (F_N/w - 1)g$

$a = (1000/700 - 1)g = 0.429g = 4.2\ \text{m/s}^2$



Elevator accelerating downward



Weight of person, w = 700 N
Apparent weight = weight read by scales, F_N = 400 N

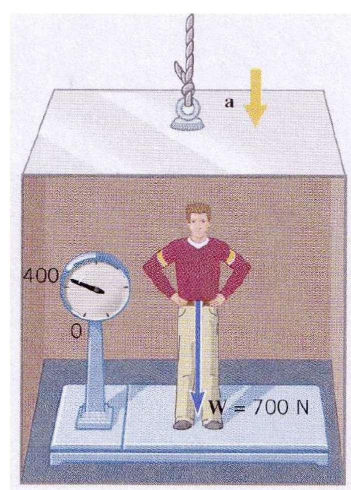
Re-using result from previous page:

$a = (F_N/w - 1)g$ in the upward direction

$a = (400/700 - 1)g = -0.43g = -4.2\ \text{m/s}^2$

Also, if $F_N = 0$ when $a = -g$

- weightless when in free fall (although gravity still acts)



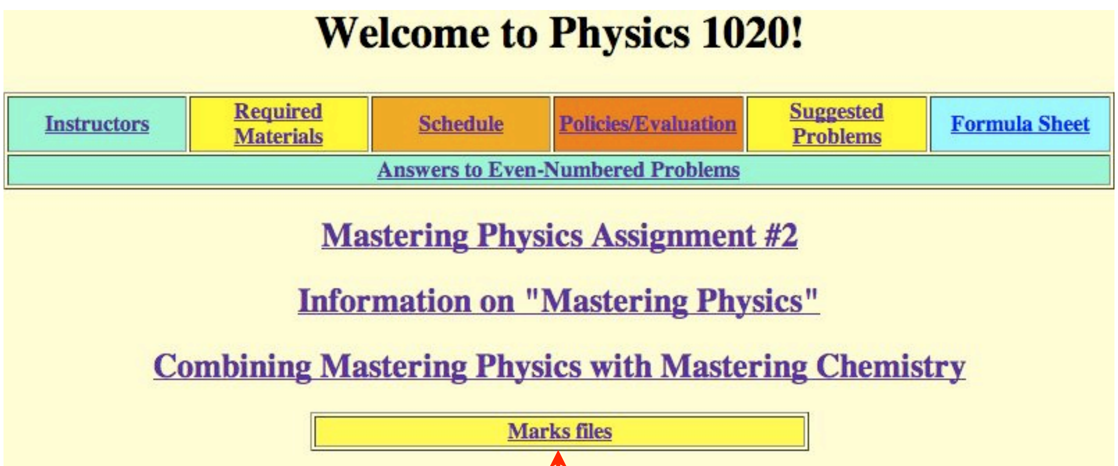
Mastering Physics Assignment 2

Is available on Mastering Physics website

Seven practice problems + six for credit on material from chapter 3

Due Wednesday, October 10 at 11 pm

On Campus Machines
Use Firefox if problems with Internet Explorer!

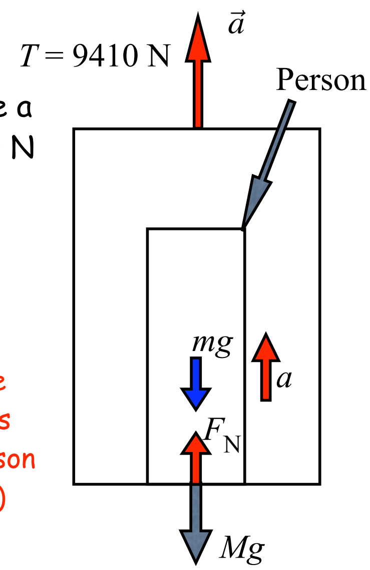


Marks for first Mastering Physics assignment (plus labs, tests when available)

http://www.physics.umanitoba.ca/~birchall/PHYS1020/

Apparent Weight

4.94/36: The person in the elevator has a mass m = 60 kg. The elevator and scale have a combined mass M = 815 kg. A force of 9410 N accelerates the elevator upwards. What is the apparent weight of the person?



The net upward force **on the person** is:

$$F_{net} = F_N - mg = ma$$

(this force accelerates just the person of mass m)

The apparent weight is F_N:

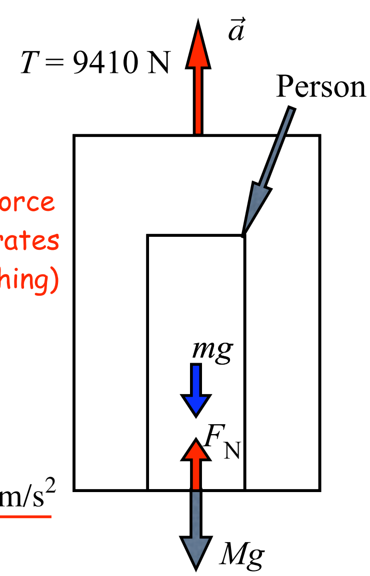
$$F_N = m(g + a)$$

So, what is the acceleration, a?

$F_N = m(g + a)$

Forces on elevator + contents

Person: m = 60 kg
Elevator + scale: M = 815 kg
Upward force on elevator: T = 9410 N



Net upward force on elevator:

(this force accelerates everything)

$$F_{net} = T - (M + m)g = (M + m)a$$

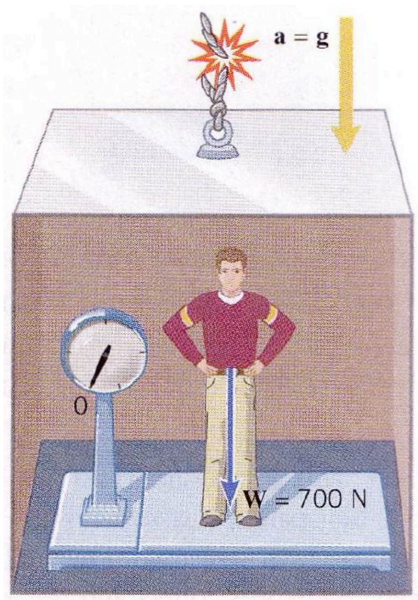
$$\text{So, } a = \frac{T - (M + m)g}{M + m}$$

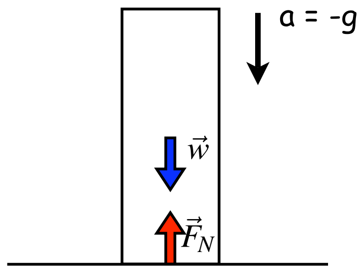
$$a = \frac{9410 - (815 + 60) \times 9.8}{815 + 60} = 0.954 \text{ m/s}^2$$

$$F_N = m(g + a) = 60 \times (9.8 + 0.954) = 645 \text{ N}$$

Scale reading = (645 N)/g = 66 kg

Apparent Weight - Free Fall: a = -g

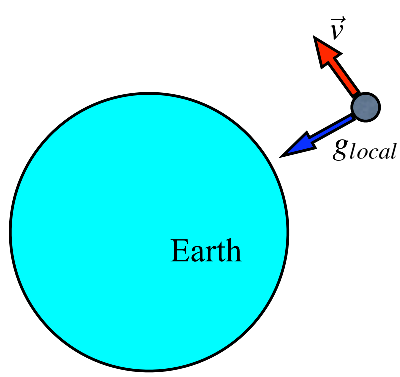




Apparent weight: $F_N = m(g + a)$

As $a = -g$, $F_N = 0$ "weightless"

Free Fall – Astronauts in Orbit

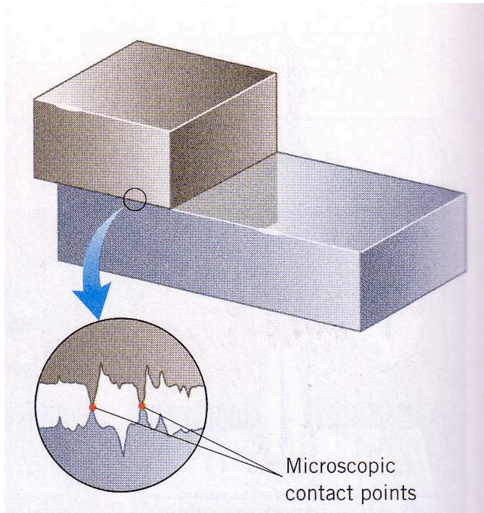


$$g_{local} = g\left(\frac{R_{earth}}{R_{orbit}}\right)^2$$

The spacecraft is accelerated toward the centre of the earth at a rate g_{local} (centripetal acceleration, chapter 5), which is the acceleration due to gravity at the radius of the orbit.

They are in free fall and "weightless". Bathroom scale reads zero.

Static and Kinetic Friction



Friction - due to uneveness of surfaces, even when polished.

Friction force increases the more the surfaces are pressed together.

Static friction - surfaces not sliding.

Kinetic friction - surfaces are sliding.

Surfaces smooth at the molecular level -

attractive inter-molecular forces bind surfaces together ("cold weld")

Static Friction

Static friction occurs when there is no sliding or skidding:

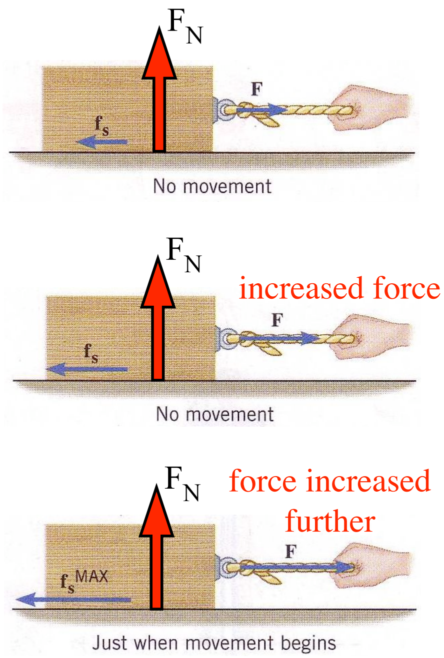
- object at rest
- car moving without skidding or spinning wheels – where the tire meets the road, the tire is momentarily at rest, so the friction is "static"

Kinetic Friction

There is sliding or skidding.

- usually less than the static friction force – hard to get an object sliding, and easier to keep it sliding.

Static Friction



The static friction force f_s opposes applied forces and increases as the applied force F is increased.

f_s rises only to a maximum value:

$$f_s^{max} = \mu_s F_N$$

and then the block slides.

$\mu_s =$ coefficient of static friction

$F_N =$ normal force

Static Friction

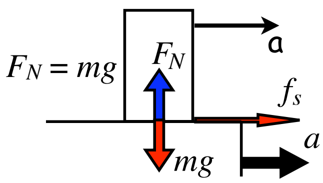
The static friction force between dry, unlubricated surfaces is:

- independent of area of contact for hard surfaces

  – not true for deformable surfaces, such as tire rubber.

4.-/38: A cup of coffee sits on a table in a plane (μ_s = 0.30). The plane accelerates. What is the maximum acceleration before the cup starts to slide?

For the cup not to slide: $f_s = ma$ (second law)



$f_s^{max} = \mu_s F_N = \mu_s mg = ma^{max}$ (2nd law)

So, $a^{max} = \mu_s g = 0.3 g$

$a^{max} = 2.94 \text{ m/s}^2$

Accelerations are often quoted as a multiple or fraction of g.
$a^{max} = 0.3 g$

Kinetic Friction

Occurs when surfaces slide. Friction force opposes the relative motion of the surfaces.

The magnitude of the kinetic friction force is:

$f_k = \mu_k F_N$

μ_k = coefficient of kinetic friction

The kinetic friction force is:

- independent of area of contact between the surfaces

- independent of relative speed of the surfaces for small speeds – high speed of sliding may cause heating and a change in the properties of the surfaces.

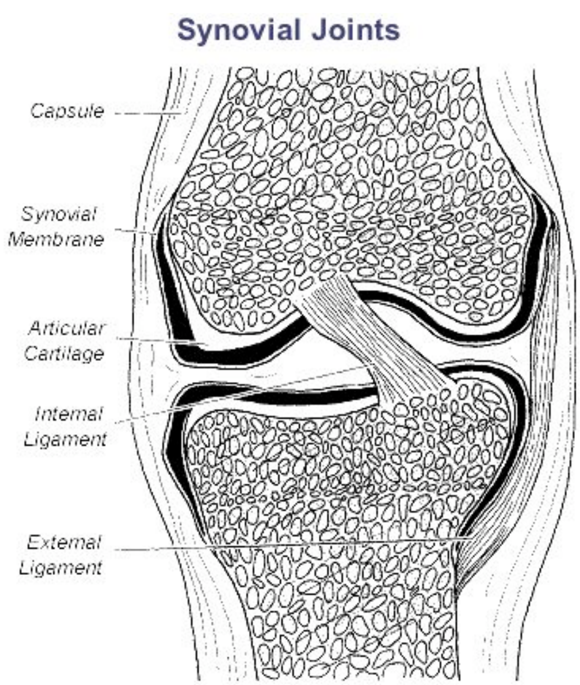
Coefficients of Friction

Materials	Coeff. of Static Friction μ_s	Coeff. of Kinetic Friction μ_k
Steel on Steel	0.74	0.57
Aluminum on Steel	0.61	0.47
Copper on Steel	0.53	0.36
Rubber on Concrete	1.0	0.8
Wood on Wood	0.25-0.5	0.2
Glass on Glass	0.94	0.4
Waxed wood on Wet snow	0.14	0.1
Waxed wood on Dry snow	-	0.04
Metal on Metal (lubricated)	0.15	0.06
Ice on Ice	0.1	0.03
Teflon on Teflon	0.04	0.04
Synovial joints in humans	0.01	0.003

Serway, Physics for Scientists and Engineers

Yahoo search –

The end of two bones which meet to form the joint are covered with articular cartilage, a surface material much like a tread of a tire. Its strength comes from tough fibers called collagen. The joint surface cartilage is well lubricated - more slippery than well-manufactured ball bearings... Its living cells are nourished by joint fluid, called synovial fluid which is also extremely good lubrication.



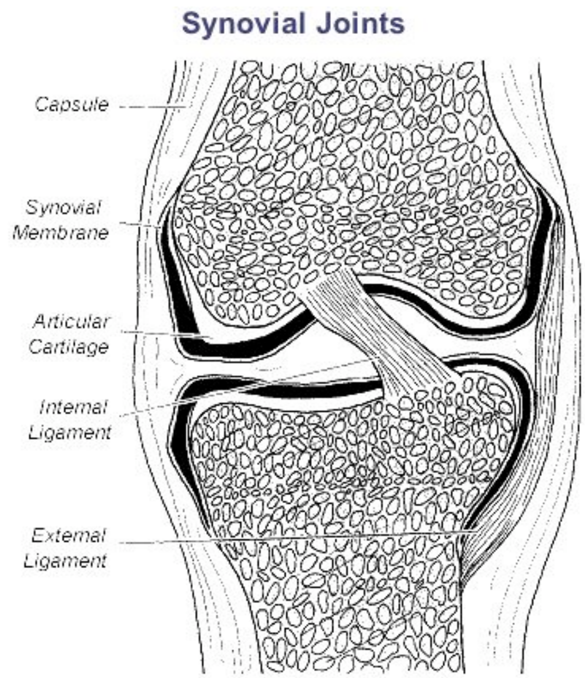
Clickers!

This is:

A) a knee joint

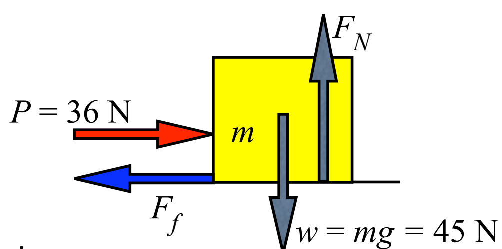
B) an elbow joint

C) some other joint



4.37: A block of weight 45 N rests on a horizontal table. Will the block move and, if so, what is its acceleration?

$\mu_s = 0.650,\ \mu_k = 0.420$



As there are only two forces with vertical components:

$F_N = w = 45$ N

The maximum static friction force is:

$F_s = \mu_s F_N = 0.65 \times 45 = 29.25$ N

This is less than the force applied, so the block starts sliding.

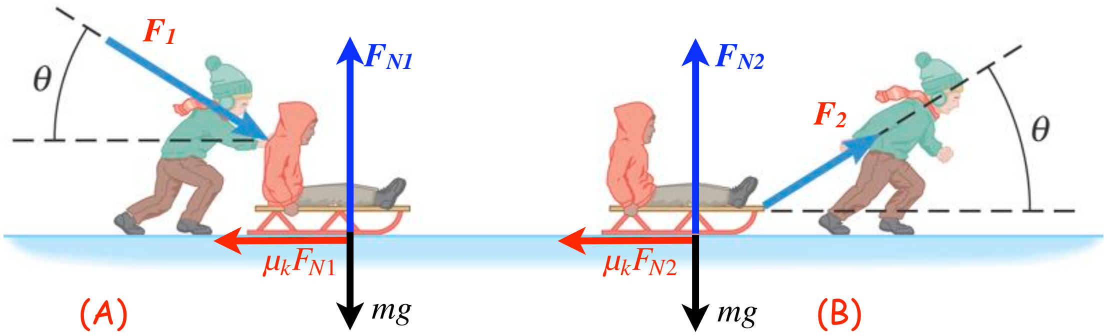
The kinetic friction force is: $F_k = \mu_k F_N = 0.42 \times 45 = 18.9$ N

The acceleration is:

$$a = F_{net}/m = (36 - 18.9\ \text{N})/(45/g\ \text{kg}) = 3.72\ \text{m/s}^2$$

Clickers!

4.C18: Which is easier – to pull or to push the sled? Friction is present.

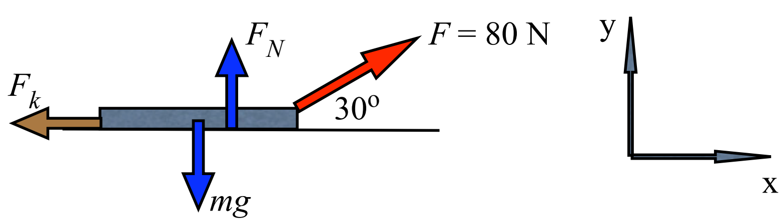


The normal force is **increased** by the downward component of $\mathbf{F_1}$

The normal force is **decreased** by the upward component of $\mathbf{F_2}$

And so the friction force is less when...

4.91/39: A 20 kg sled is pulled across a horizontal surface **at constant speed**.



What is the coefficient of kinetic friction?

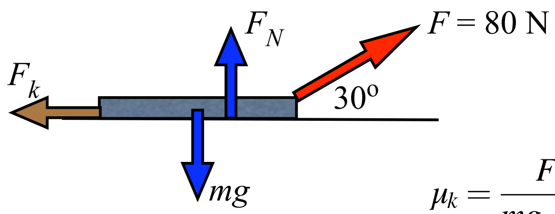
Speed is constant, so net force on sled = 0.

x direction: $F\cos 30^\circ = F_k = \mu_k F_N$ so, $F_N = F\cos 30^\circ / \mu_k$

y direction: $F\sin 30^\circ + F_N = mg$ and, $F_N = mg - F\sin 30^\circ$

$$\text{Therefore, } F_N = \frac{F\cos 30^\circ}{\mu_k} = mg - F\sin 30^\circ$$

$$F_N = \frac{F\cos 30^\circ}{\mu_k} = mg - F\sin 30^\circ$$



$$\mu_k = \frac{F\cos 30^\circ}{mg - F\sin 30^\circ}$$

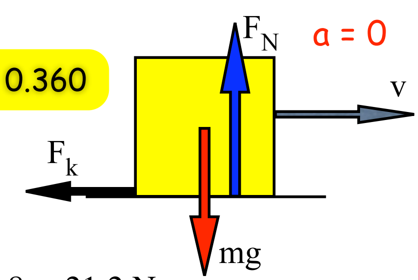
Substitute $F = 80$ N, $m = 20$ kg

$$\mu_k = \frac{80\cos 30^\circ}{20 \times 9.8 - 80\sin 30^\circ} = 0.444$$

4.40: A 6 kg box slides across the floor of an elevator. Find the kinetic frictional force.

(a) Elevator at rest

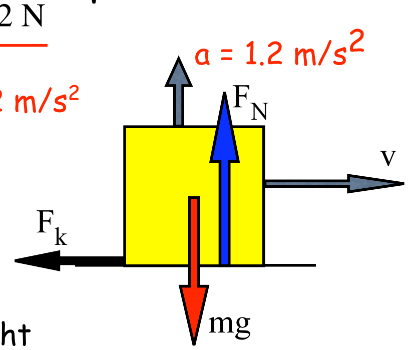
$\mu_k = 0.360$



$$F_k = \mu_k F_N \text{ and } F_N = mg$$

So $F_k = \mu_k mg = 0.36 \times 6 \times 9.8 = 21.2$ N

(b) Elevator accelerated upward at 1.2 m/s^2

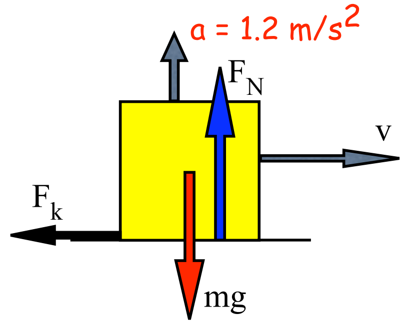


Work out the force needed to accelerate the box upward.

$$F_N - mg = ma$$

So $F_N = m(g + a)$ = apparent weight

$$\boxed{\text{So } F_N = m(g+a)}$$



$$F_k = \mu_k F_N = \mu_k \times m \times (g+a)$$

$$F_k = 0.36 \times 6 \times (9.8 + 1.2) = 23.8 \text{ N}$$

(c) Elevator accelerated downward at 1.2 m/s^2

Use a = –1.2 m/s^2 and proceed as above:

$$F_k = 0.36 \times 6 \times (9.8 - 1.2) = 18.6 \text{ N}$$

Mastering Physics Assignment 2

Is available on Mastering Physics website

Seven practice problems + six for credit on material from chapter 3

Due Wednesday, October 10 at 11 pm

On Campus Machines

Use Firefox if problems with Internet Explorer!

GENERAL PHYSICS I: PHYS 1020

Schedule - Fall 2007
(lecture schedule is approximate)

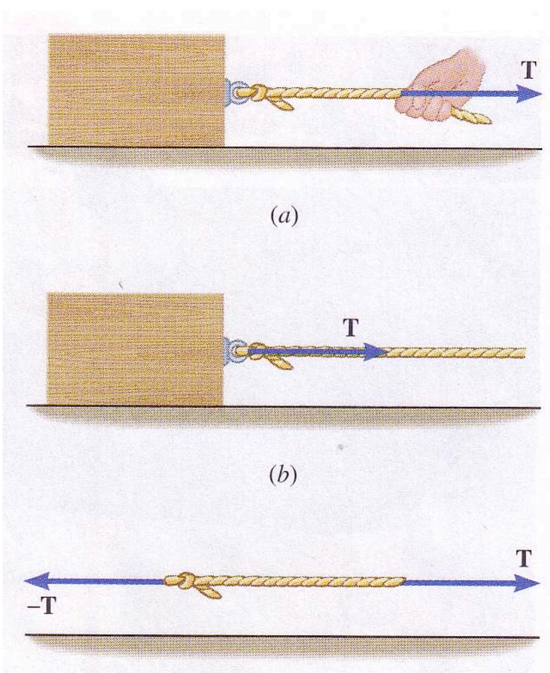
5	M	Oct 1	11			Tutorial and Test 1 (chapters 1, 2, 3)
	W	3	12	Chapter 5	Uniform circular motion	
	F	5	13			
6	M	8	Thanksgiving Day			Experiment 2: Measurement of g by free fall
	W	10	14	Chapter 5	Uniform circular motion	
	F	12	15	Chapter 6	Work and energy	
7	M	15	16			Tutorial and Test 2 (chapters 4, 5)
	W	17	17			
	F	19	18	Chapter 7	Impulse and momentum	
8	M	22	19			No lab or tutorial
	Tue	23	MID-TERM TEST, Ch 1-5, Tuesday, October 23, 7-9 pm			
	W	24	20	Chapter 7	Impulse and momentum	
	F	26	21	Chapter 8,	Rotational kinematics	

Week of October 8

Monday is a holiday!

Experiment 2: Measurement of g by free fall

The Tension Force



Tension – the force within a rope or cable that is used to pull an object.

A force **T** applied to the end of the rope is transferred to other end of the rope where it exerts the same force on the block.

The block exerts an equal and opposite force on the rope (Newton's 3rd law).

Objects in Equilibrium

An object is in equilibrium when its acceleration is zero – it remains at rest, or moves with constant velocity.

This implies that the net force acting on it is zero (first law).

$$F_x^{net} = 0$$
$$F_y^{net} = 0$$

- Equilibrium is often expressed in terms of the net force on an object being zero.

- The object may be moving, but at constant velocity.

Objects not in Equilibrium

Apply Newton's second law to motion in x and y:

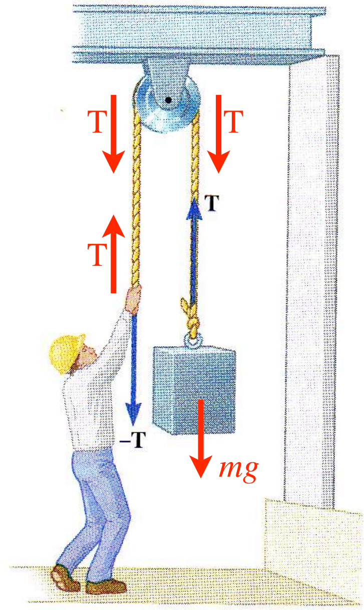
$$F_x^{net} = ma_x$$
$$F_y^{net} = ma_y$$

The Tension Force

The man pulls the rope with a force T.

The force is transmitted undiminished over the pulley (massless rope, frictionless pulley) and exerts an upward force T on the block.

If the block is in equilibrium: T = mg



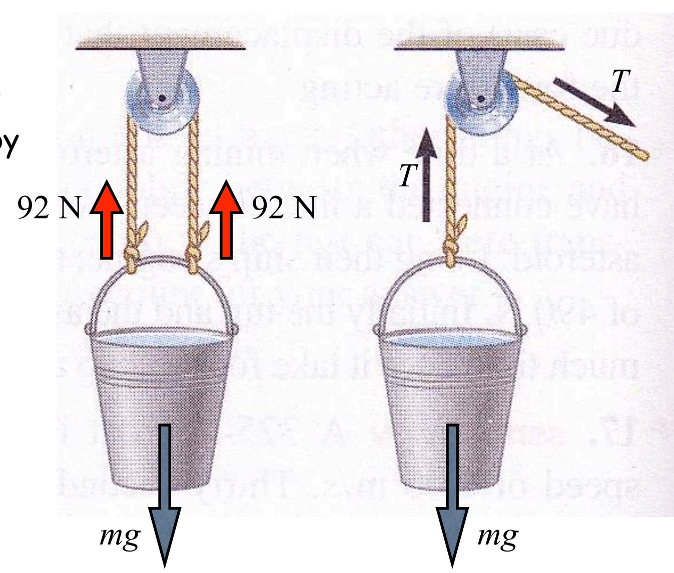
4.48/46: In the left hand diagram, the tension in the rope is 92 N. What is the tension in the right hand diagram?

The weight of the bucket on the left is supported by two tensions forces:

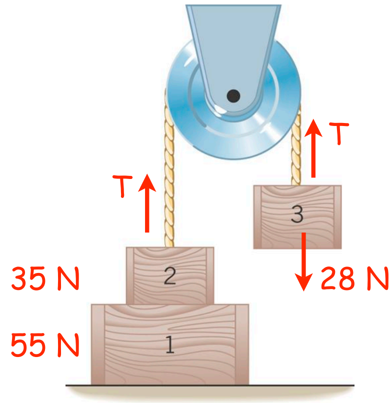
$mg = 92 + 92 = 184$ N

T in diagram at right is alone supporting the bucket. So,

$T = 184$ N



Clickers!



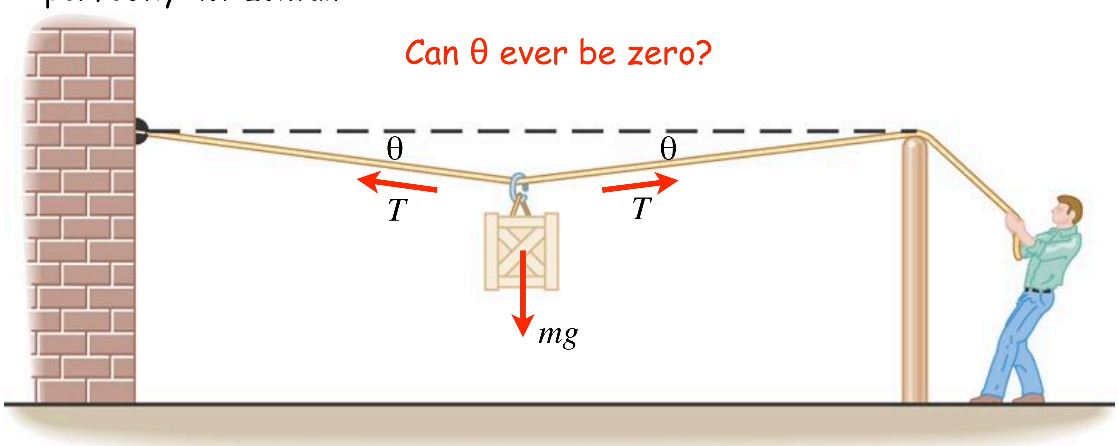
4.55: Box 1 is resting on a table with box 2 on top of box 1. A massless rope passes over a frictionless pulley to box 3. The weights of the boxes are:

W_1 = 55 N
W_2 = 35 N
W_3 = 28 N

The magnitude of the normal force that the table exerts on box 1 is:

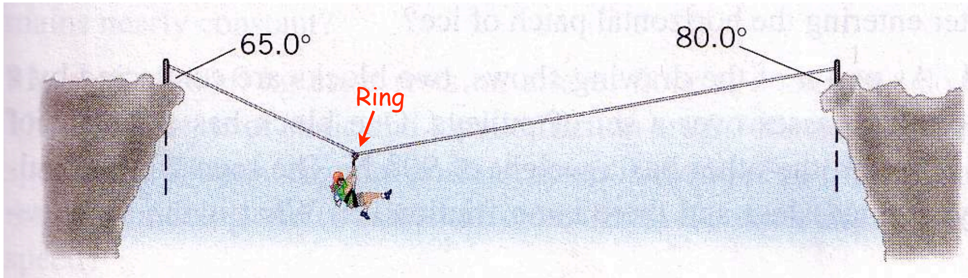
A) 55 N
B) 62 N ←
C) 90 N
D) 118 N
E) I made a mistake

4.C26: Can the person who is pulling the rope ever make the rope perfectly horizontal?



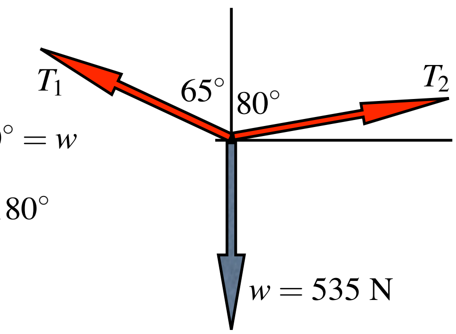
To support the weight:

$$mg = 2T\sin\theta$$



4.102/58: The mountaineer weighs 535 N. What are the tensions in the two sections of the cable?

Forces on the ring:



Vertically: $T_1 \cos 65^\circ + T_2 \cos 80^\circ = w$

Horizontally: $T_1 \sin 65^\circ = T_2 \sin 80^\circ$

Eliminate T_1, solve for T_2

Vertically: $T_1 \cos 65^\circ + T_2 \cos 80^\circ = w$ (1)

Horizontally: $T_1 \sin 65^\circ = T_2 \sin 80^\circ$ (2)

So, $T_1 = T_2 \dfrac{\sin 80^\circ}{\sin 65^\circ} = 1.0866 \times T_2$ (2)

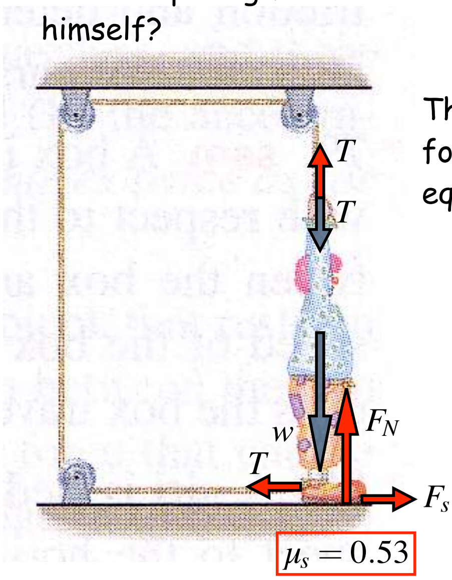
Substitute into (1):

$T_2 \times 1.0866 \cos 65^\circ + T_2 \cos 80^\circ = w = 535$ N

$T_2 = 535/0.63287 = 845$ N

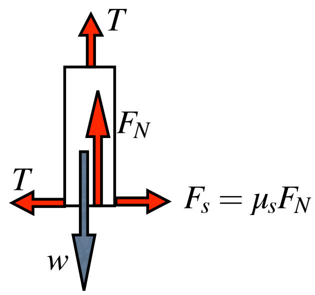
and $T_1 = 1.0866 \times T_2 = 918$ N

4.54: A circus clown weighs 890 N. He pulls vertically on the rope that passes over three pulleys and is tied to his feet. What is the minimum pulling force needed to yank his feet out from beneath himself?



The clown pulls down on rope with force T. The rope pulls back with equal force.

Forces acting on the clown:



If T > F_s, his feet will slip

If T > F_s, his feet will slip.

That is: (maximum value)

$$T > F_s = \mu_s F_N \rightarrow \text{set } T = \mu_s F_N$$

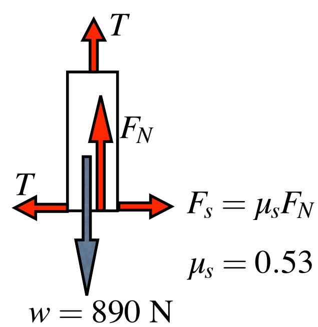
What is F_N?

Forces in the vertical direction:

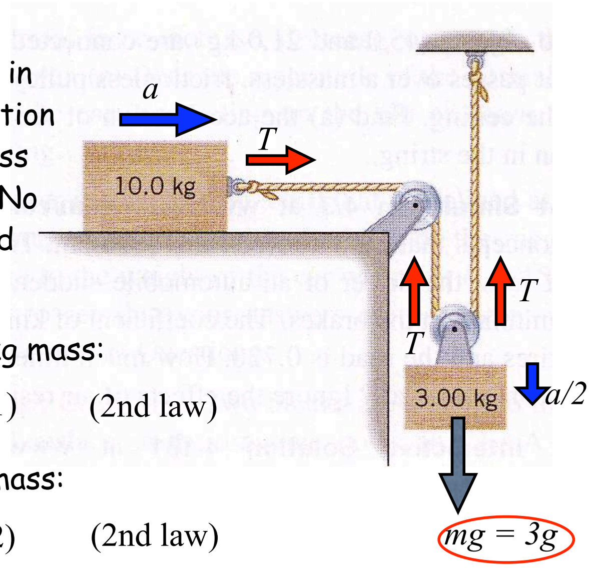
$$T + F_N = w = 890 \text{ N} \quad \text{or} \quad \mu_s F_N + F_N = 890 \text{ N}$$

So, $F_N = (890 \text{ N})/(1 + 0.53) = 582 \text{ N}$

Substitute $T = \mu_s F_N = 0.53 \times 582 = 308 \text{ N}$



4.83/85: Find the tension in the rope and the acceleration of the 10 kg mass (massless rope, frictionless pulley). No friction between block and table.



Force to the right on 10 kg mass:

$$T = ma = 10a \qquad (1) \qquad \text{(2nd law)}$$

Downward force on 3 kg mass:

$$3g - 2T = 3(a/2) \qquad (2) \qquad \text{(2nd law)}$$

So, from (1) and (2): $2T = \boxed{20a = 3g - 3a/2}$

Therefore, $a = 1.37\ \text{m/s}^2$ and $T = 10a = 13.7\ \text{N}$

All of the physics so far –

- Force, mass and Newton's three laws of motion
- Newton's law of gravity
- Normal, friction and tension forces.
- Apparent weight, free fall
- Equilibrium

The rest is –

- useful equations – the four famous equations
- how to apply all of the above