Forces and gravitation slide deck

Physics 20

Unit B: Forces and gravitation

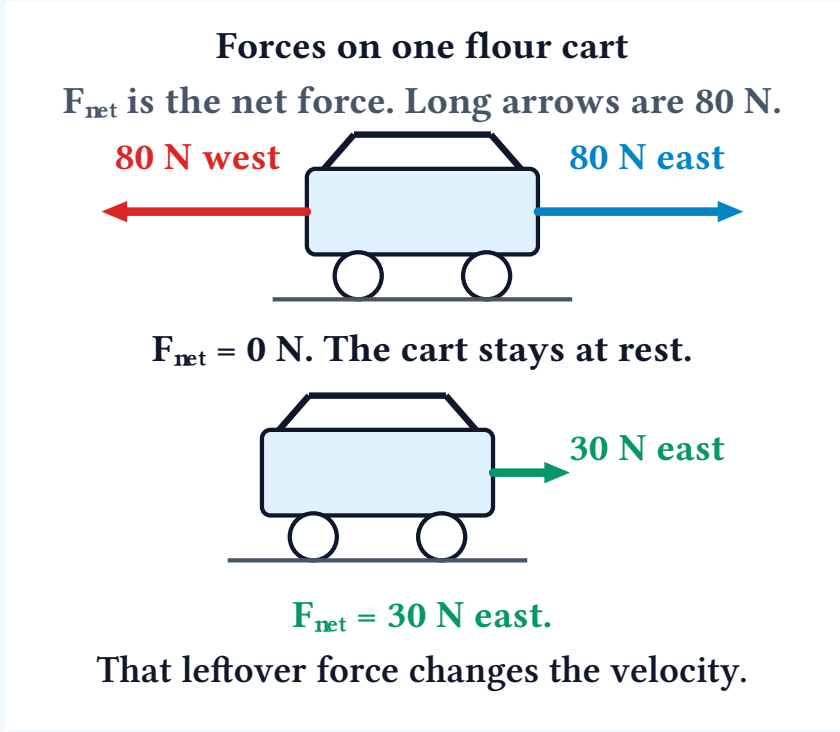
Net force and Newton's first law

A flour cart in an Airdrie aisle

- Two workers push a flour cart with 80 N east and 80 N west, and the cart stays at rest.
- A third push of 30 N east leaves a resultant of 30 N east, and the cart’s velocity starts to change.

Net force and inertia

- Net force, written F_{net}, is the vector sum of every force on one object.
- A net force with magnitude above zero changes velocity.
- When the forces on one object add to zero, the object stays at rest or keeps a steady velocity. That tendency is inertia.



Key terms

net force

Net force is the vector sum of every force on an object, with magnitude and direction. (F_{net})

inertia

Inertia is the tendency of an object to keep its current state of rest or uniform motion.

Newton's first law

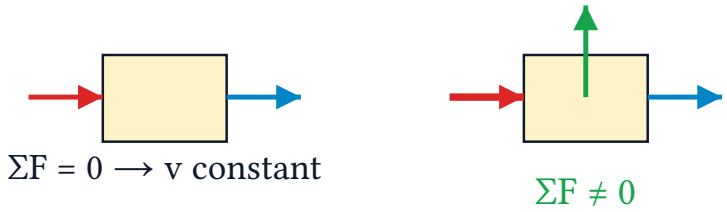
Newton's first law says an object stays at rest or in uniform motion when the net force is zero.

balanced forces

Balanced forces are forces on one object that sum to a zero resultant.

A resultant above zero changes velocity

- Add forces on one object by direction before you predict the motion.
- A net force with magnitude above zero changes the velocity.
- Equal opposing forces on the same object leave a zero resultant.



Add forces by direction on one object

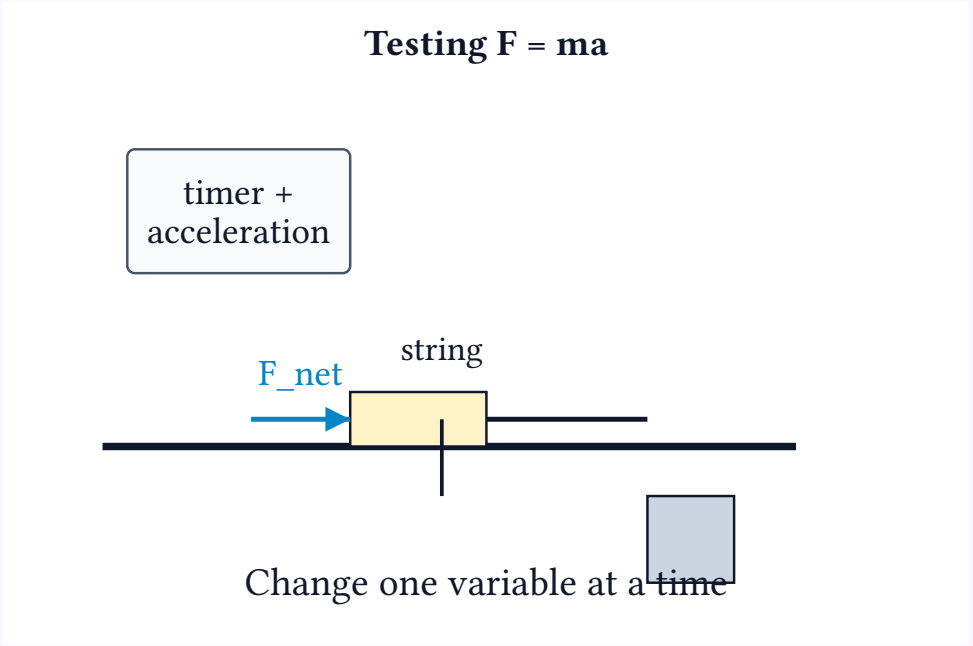
Resultant changes velocity when |ΣF| > 0

Three ropes on a crate skid

- A 6.0 kg skid has ropes of 25 N east, 10 N west, and 9.0 N east.
- The resultant is 24 N east, so the velocity changes toward the east.
- Balanced forces would require that vector sum to be 0 N.

Testing the second law

- The investigation question asks how acceleration, mass, and force are related.
- Change one manipulated variable at a time and record acceleration with a timer.
- Clear the track, catch the cart, and wear eye protection on every run.



A hallway bin with two pushes

- A hallway bin receives 48 N north and 48 N south.
- Decide whether the forces are balanced and what the velocity does.
- Then replace the south push with 33 N south and describe the new resultant.

Rest and a shove

- A curling stone slides east at a steady 2.0 m/s while the forces on it add to 0 N.
- State the law and the role of inertia for that glide.
- A later 4.0 N south force becomes the only remaining force. Describe the velocity.

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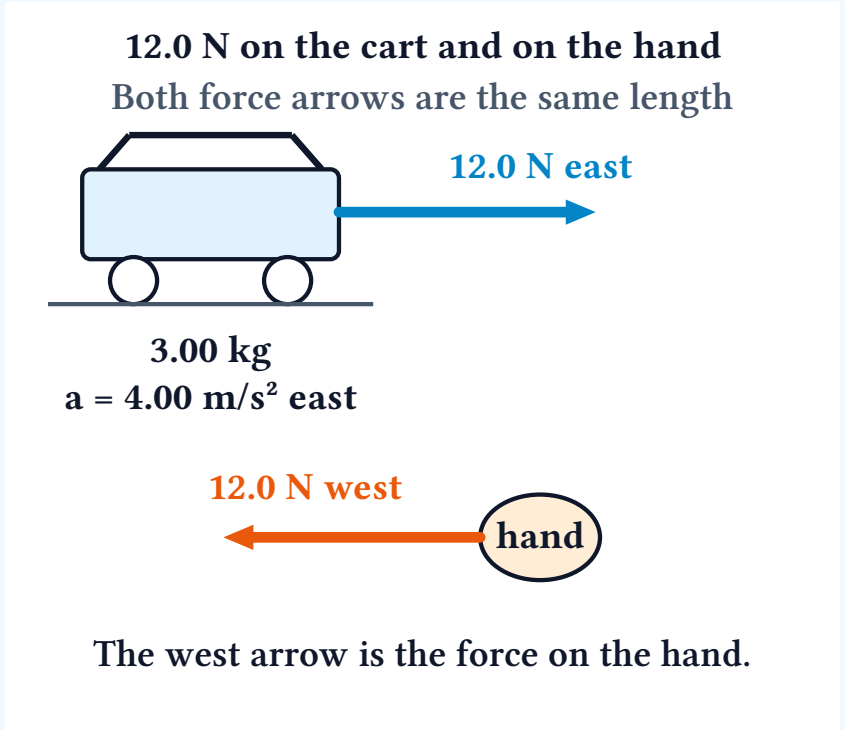
Newton’s second and third laws

A spring scale on a lab cart

- A spring scale pulls a 3.00 kg cart with 12.0 N east. That pull is the only horizontal force in the problem.
- The acceleration is 4.00 m/s squared east, and the student’s hand feels a matching pull west.

Newton's second and third laws

- F_{net} means the net force, m means the mass, and a means the acceleration.
- Newton's second law says F_{net} equals m times a.
- Newton's third law places equal magnitude forces on two different objects.
- A free body diagram keeps only the forces on the chosen object.



Key terms

Newton’s second law

Newton’s second law says the net force equals mass times acceleration, written $F_{net} = m\ a$. ($F_{net} = m\ a$)

Newton’s third law

Newton’s third law says the two forces in a pair have equal magnitude and opposite direction, and each force acts on a different object.

free body diagram

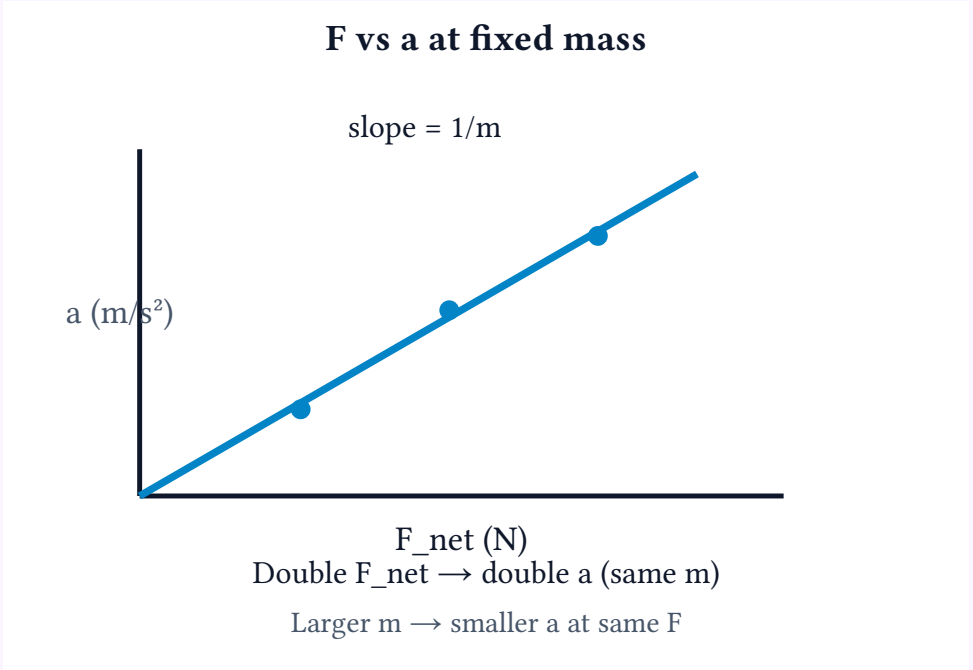
A free body diagram shows only the forces on the chosen object, drawn as arrows on a simple outline.

mass

Mass is the amount of matter in an object, measured in kilograms, and it sets how large an acceleration a given net force produces. (m)

Force and acceleration graph

- Same mass: double the net force and the acceleration doubles.
- At a fixed net force, a larger mass goes with a smaller acceleration.
- A timer supplies delta v over delta t for each run.

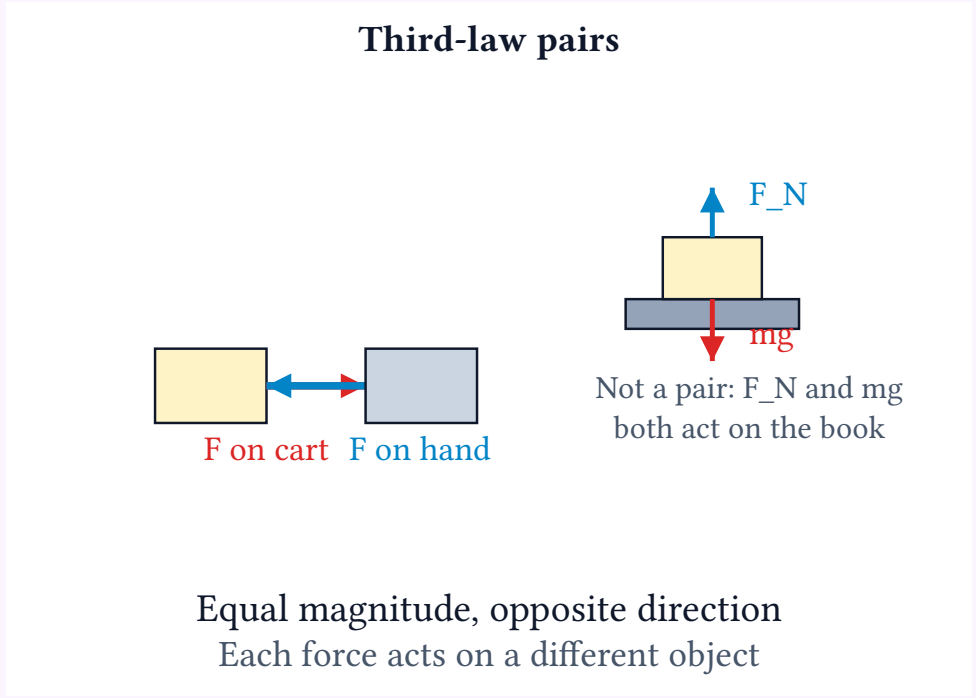


Three ways to state 4.00 m/s squared

- In numbers: the 3.00 kg cart gains 4.00 m/s squared east.
- In symbols: 12.0 N / 3.00 kg = 4.00 m/s^2 east.
- On a graph: the mass is the slope of the force versus acceleration line.

Partner forces land on different objects

- The two forces in the pair have equal magnitude and opposite direction.
- Each force acts on a different object, so the accelerations can differ.
- A free body diagram of a book shows weight and the normal force from the desk.



A wagon and a book outline

- A 2.50 kg wagon has a net force of 7.50 N forward.
- Find the acceleration and name the third law partner on the puller’s hand.
- List the forces on a free body diagram of a lunch bag sitting on a table.

Newton’s laws

- A 4.00 kg crate has a net force of 10.0 N south.
- Find the acceleration and the partner force on the rope.
- Name the forces on a free body diagram of the crate if the pull is horizontal on a level floor.

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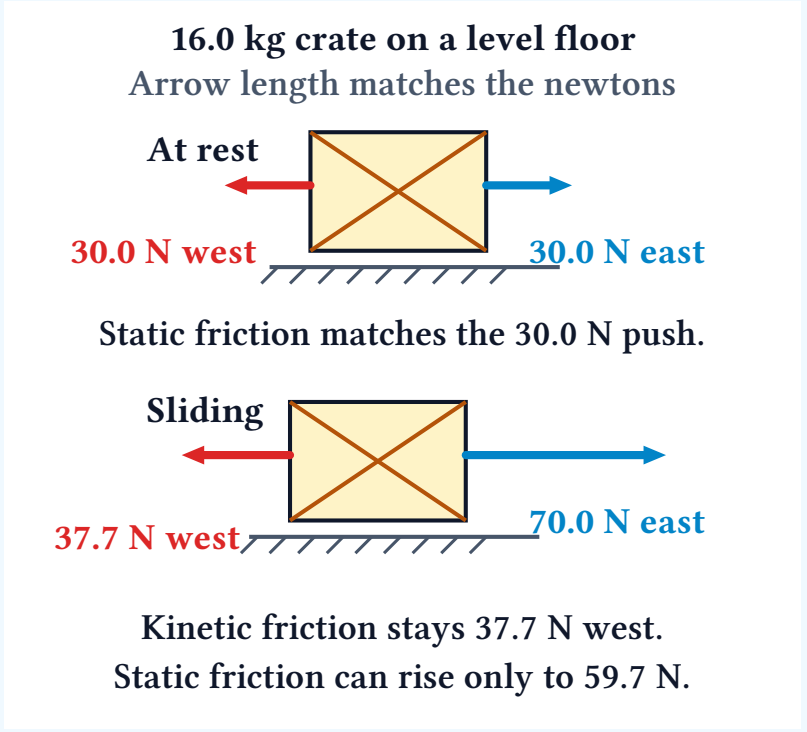
Friction and vector forces

A 16.0 kg crate that waits, then slides

- A 16.0 kg crate on a level warehouse floor stays at rest under a 30.0 N horizontal push.
- The same crate slides once the push reaches 70.0 N, with friction still opposing the motion.

Friction and resultant force

- Static friction uses μ_s, the coefficient of static friction, and it matches your push up to μ_s times the normal force.
- Kinetic friction uses μ_k, the coefficient once the crate is sliding, and it equals μ_k times the normal force.
- The east and north ropes can be replaced by one arrow with a single length and a single direction.



Key terms

static friction

Static friction adjusts up to a maximum of μ_s times the normal force and holds the contact at rest. (f_s max = μ_s N)

kinetic friction

Kinetic friction equals μ_k times the normal force and points opposite the sliding motion. ($f_k = \mu_k$ N)

normal force

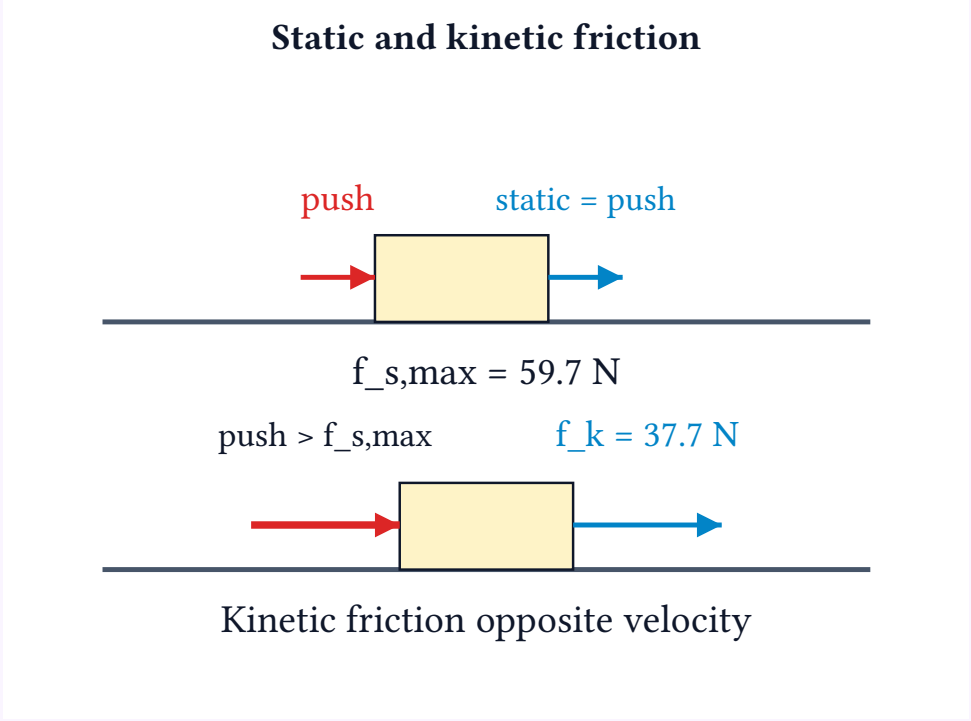
The normal force is the support force a surface exerts perpendicular to the surface. (N)

resultant

The resultant is the single vector that replaces two or more component vectors, with magnitude and direction.

Static and kinetic friction

- Below the maximum, static friction equals the applied push and the crate stays at rest.
- The maximum static friction for the crate is 59.7 N.
- Once sliding starts, kinetic friction stays at 37.7 N opposite the velocity.

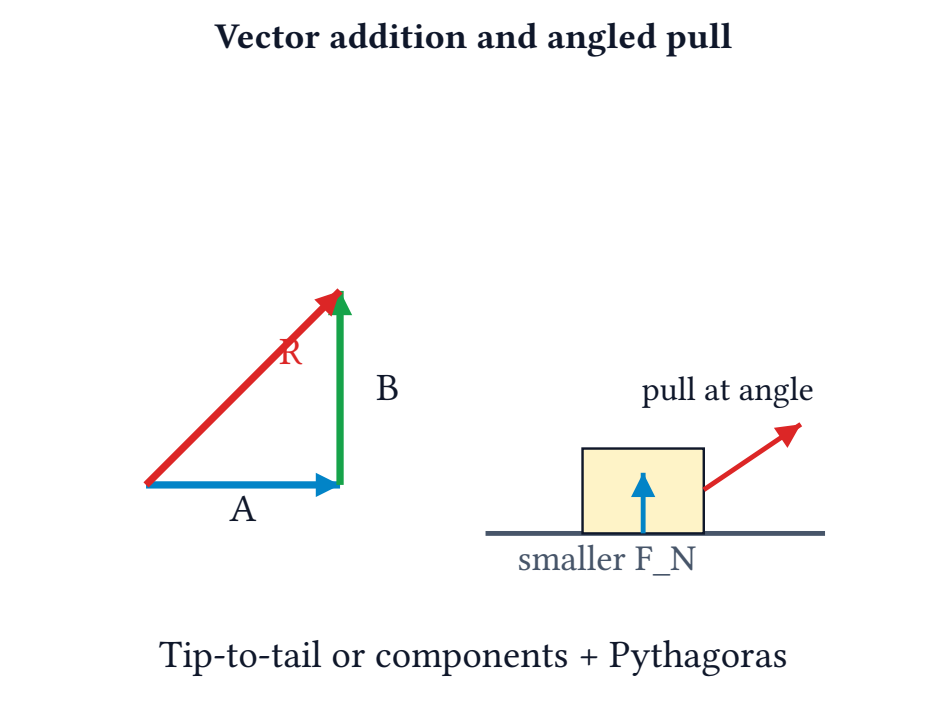


Acceleration once the crate slides

- A 70.0 N east push acts while kinetic friction is 37.7 N west.
- The horizontal net force is 32.3 N east.
- The acceleration of the 16.0 kg crate is 2.02 m/s squared east.

Components on paper and on a grid

- Draw the arrows tip to tail. The closing arrow is the one resultant.
- Or square each leg, add, take the square root, and use inverse tan for the angle.
- A pull with an upward angle lifts a little, so the floor pushes up with a smaller normal force.



A 30.0 N closing arrow

- Ropes of 18.0 N west and 24.0 N south act on a sled.
- Find the resultant magnitude and the angle south of west.
- State which component is adjacent to that angle.

Drag and a diagonal

- A 10.0 kg bin on a level floor has μ_k of 0.200, and its normal force equals its weight.
- Find the kinetic friction, aimed opposite the slide.
- Then find the resultant of 9.0 N east and 12.0 N north.

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Motion on planes

Inclines and elevators

- An 8.00 kg sled is in a hallway.
- A 70.0 kg rider is in an elevator.
- A 2.50 kg cart is on a 30.0 degree ramp.
- Draw a separate arrow diagram for the sled, the elevator, and the ramp. Air is left out of the arithmetic.

Three surfaces, two weight components

- A level floor keeps one horizontal axis and one vertical axis.
- An elevator keeps upward as positive while the car accelerates.
- An inclined plane splits weight into a parallel component and a perpendicular component.

Key terms

inclined plane

An inclined plane is a flat surface set at an acute angle to the horizontal axis. (theta)

parallel component

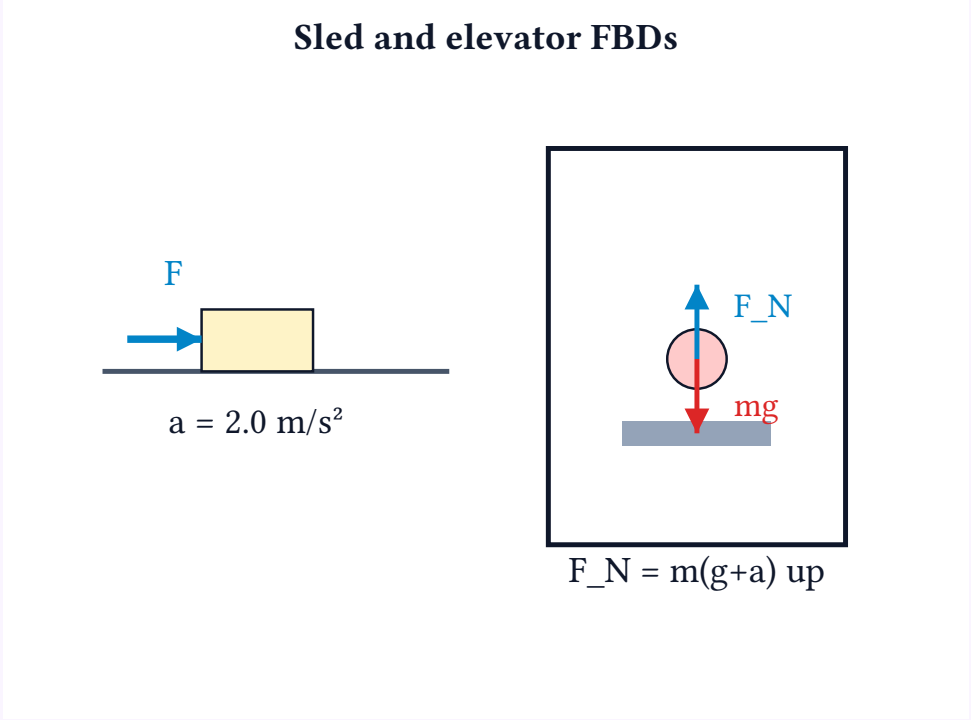
The parallel component of weight is m g sin theta, directed down the incline. Here m is mass, g is 9.81 m/s squared downward, and theta is the angle from the horizontal. (m g sin theta)

perpendicular component

The perpendicular component of weight is m g cos theta, directed into the incline. The same m, g, and theta are the mass, the field strength, and the ramp angle. (m g cos theta)

Hallway arithmetic and the elevator floor

- The hallway sled accelerates at 2.00 m/s squared forward.
- Upward is positive in the elevator, so the normal force is m times the quantity g plus a.
- The hallway sled and the elevator use only the forces on the diagram. Air is left out.

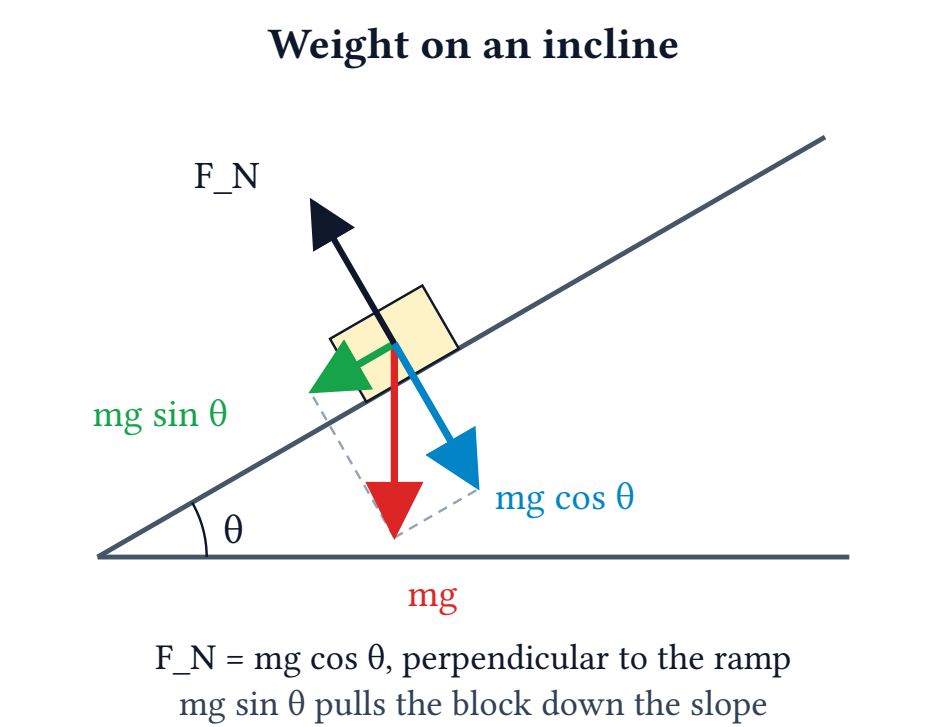


A 30.0 degree cart

- Parallel: (2.50 kg)(9.81)(sin 30) = 12.3 N down the ramp.
- Perpendicular: (2.50 kg)(9.81)(cos 30) = 21.2 N into the ramp.
- Friction free: 12.3 N / 2.50 kg = 4.91 m/s^2 down the ramp.

Weight component into the ramp

- The perpendicular component is m g cos theta into the surface.
- On a friction free incline the normal force matches that perpendicular component.
- Measure the ramp angle from the horizontal, and keep that angle under 90 degrees.



A rider accelerating upward

- A 55.0 kg rider accelerates upward at 1.20 m/s squared.
- Take upward as positive and find the floor’s normal force.
- Compare that force with the rider’s weight.

A 20 degree ramp

- A 4.00 kg crate rests on a friction free ramp at 20 degrees to the horizontal.
- Find the parallel component and the perpendicular component.
- Find the acceleration down the incline.

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Dynamics in society

Two stops from 12 m/s

- A 60 kg occupant slows by 12 m/s in 0.050 s during a rigid stop, which takes 14400 N.
- The same velocity change spread over 0.20 s in a crumple zone takes 3600 N.

Forces in daily life

- A seat belt or a crumple zone makes the slow down last longer, so the force stays smaller.
- Head Smashed In is a buffalo jump the community planned so the herd would supply meat and hides.
- Talk about seat belts with Newton’s first law: the passenger keeps moving until a force changes that velocity.

Key terms

injury prevention device

An injury prevention device lengthens the time of a velocity change so the force on a person stays smaller.

buffalo jump

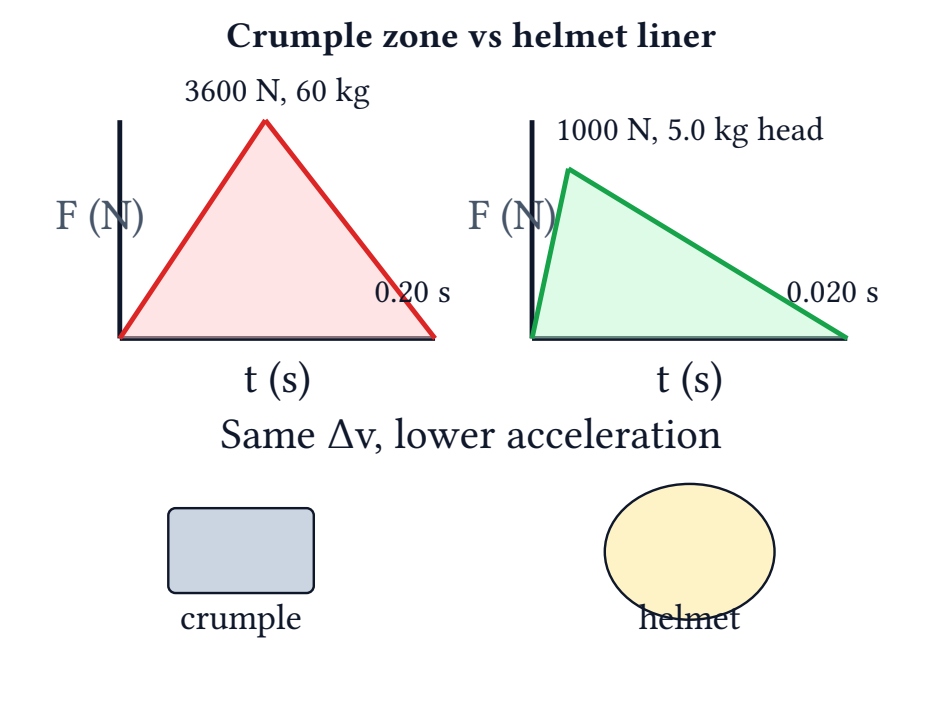
A buffalo jump is a coordinated cliff drive technology that supplied a community harvest of bison.

seat belt

A seat belt is a strap that exerts a force so a passenger's velocity changes with the vehicle.

Crumple metal and a crushing liner

- The crumple case uses 0.20 s and a 3600 N force on the 60 kg occupant.
- The helmet liner uses 0.020 s and a 1000 N force on the 5.0 kg head model.
- Both devices keep the velocity change and lower the acceleration.



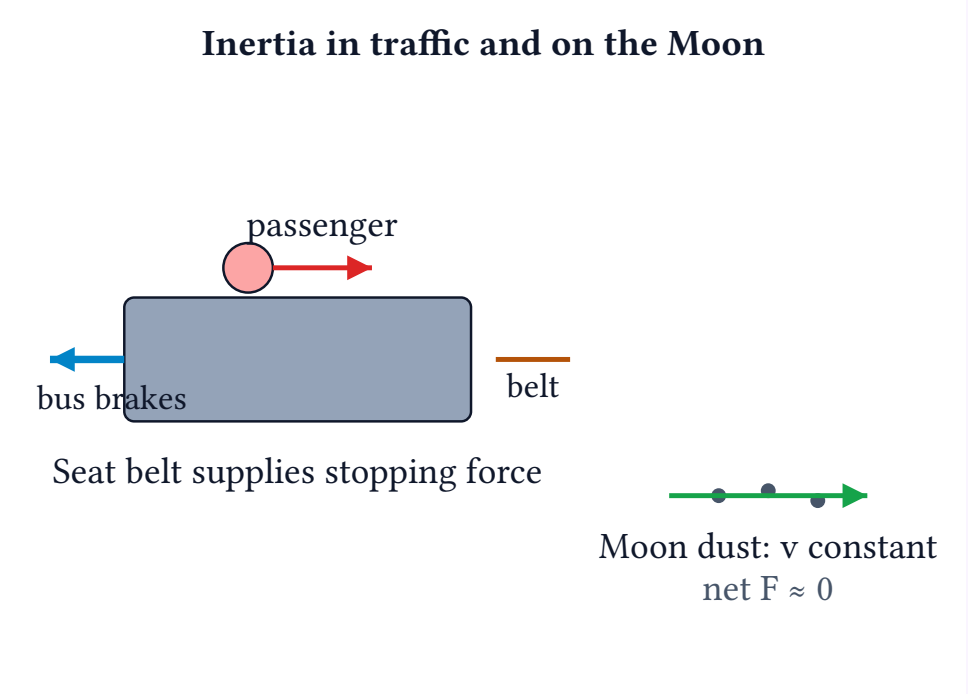
Head Smashed In as planned technology

- Niitsitapi runners and cairn lanes guided bison toward the cliff.
- A successful drive produced a community harvest of meat and hides.
- The drive depended on herd movement, cliff danger, and timing.



A braking bus and moon dust

- A passenger keeps the bus's earlier velocity until a force changes it.
- A seat belt or a tall padded seat back can supply that force.
- Lunar dust keeps a steady velocity after a kick because the net force is about zero.



One shared sentence about the bus

- Each person contributes one first law fact about the 15 m/s bus.
- The group writes a single sentence that includes a seat belt and a force.
- A second sentence says what the tall seat back does.

Forces in society

- A helmet stretch of 0.040 s changes a 4.0 m/s head velocity on a 5.0 kg model.
- Find the force and name the device.
- Add one sentence on the buffalo jump’s community harvest and one on a seat belt.

Image credits

Ken Thomas, Head-Smashed-In Buffalo Jump-27527-2, public domain

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Unit B: Forces and gravitation

Universal gravitation

Two lead spheres on a bench

- A 20.0 kg sphere and a 5.00 kg sphere, centres 0.150 m apart, attract each other.
- The same pattern of attraction reaches from an apple to Earth and from Earth to the Moon.

A fundamental attraction and its constant

- Gravity pulls every pair of masses toward each other.
- F is the pull, G is the gravity constant, m1 and m2 are the masses, and r is the centre to centre distance.
- Universal gravitation writes F = G m1 m2 / r squared, and G equals 6.67e-11 N m squared per kg squared.

Key terms

gravitational force

Gravitational force is the attractive force between two masses, directed along the line that joins their centres. (F)

universal gravitation

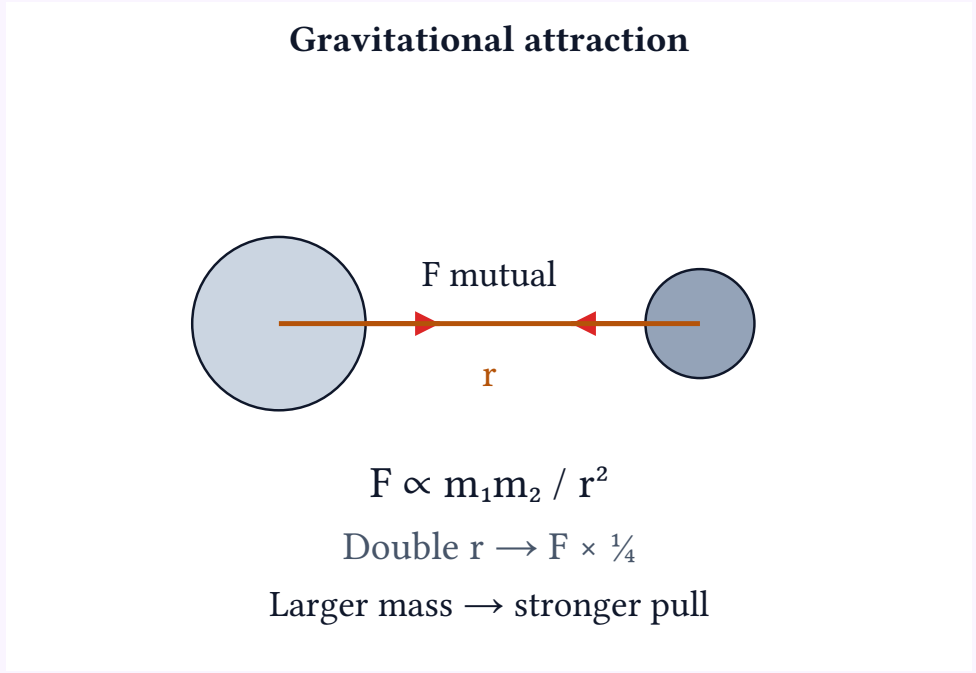
Universal gravitation is the law that every pair of masses attracts with F = G m1 m2 / r squared. ($F = G\ m1\ m2 / r^2$)

gravitational constant

The gravitational constant G is 6.67e-11 N m squared per kg squared, the number that sets the strength of the attraction. (G)

Masses strengthen it, distance weakens it

- A larger mass on either side increases the gravitational force.
- Doubling the centre to centre distance multiplies the force by one quarter.
- The attraction is mutual and lies on the line of centres.



The bench sphere calculation

- F = (6.67e-11)(20.0)(5.00) / (0.150 m)².
- G is 6.67e-11 N m squared per kg squared.
- The gravitational force magnitude is 2.96e-7 N.

A fibre that measured G

- Cavendish used a torsion balance with small masses on a suspended rod.
- Large masses attract the small masses and the torsion fibre twists.
- The twist measures the gravitational force and therefore measures G.



Equal 10.0 kg spheres

- Two 10.0 kg spheres have centres 0.200 m apart.
- Compute r squared first.
- Find the gravitational force magnitude.

A new pair

- Masses of 4.00 kg and 9.00 kg have centres 0.300 m apart.
- Find the gravitational force magnitude.
- State what a torsion fibre twist measured in Cavendish’s experiment.

Image credits

GOKLuLe 盧樂, Cavendish experiment 3, CC BY-SA 3.0

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Unit B: Forces and gravitation

Gravitational field and weight

The same student, two readings

- A 55.0 kg student weighs 540 N on Earth, where the field strength is 9.81 N/kg downward.
- On the Moon the same mass weighs 89.1 N because the field strength there is 1.62 N/kg.

Force per kilogram at a place

- A gravitational field states the force per kilogram at a place.
- Symbol g is the field strength, G is the gravity constant, M is the source mass, and r is the distance from the centre.
- Weight is the gravitational force F_g. It equals mass m times field strength g, so g also equals F_g divided by m.

Key terms

gravitational field

A gravitational field describes the gravitational force per kilogram at a place. (g)

weight

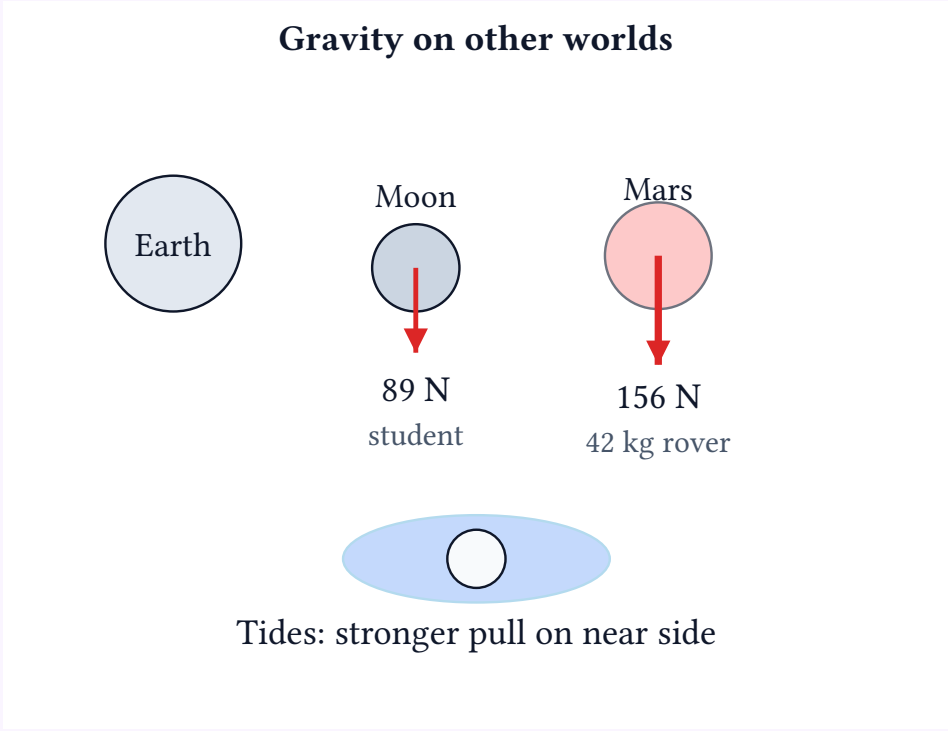
Weight is the gravitational force on an object, equal to mass times the local field strength. ($F_g = m\ g$)

field strength

Field strength is the force per kilogram at a place, g = G M / r squared and also $g = F_g / m$. ($g = G\ M / r^2$)

Gravity on other worlds

- Weight on the Moon for this student is 89.1 N, and on Mars a 42.0 kg rover weighs 156 N.
- Tides come from a difference in Earth's pull across the ocean.
- A globular cluster is a tight ball of stars held by their mutual pulls.
- On Mars the rover weighs less, so the motor force for the same acceleration up the ramp is smaller.

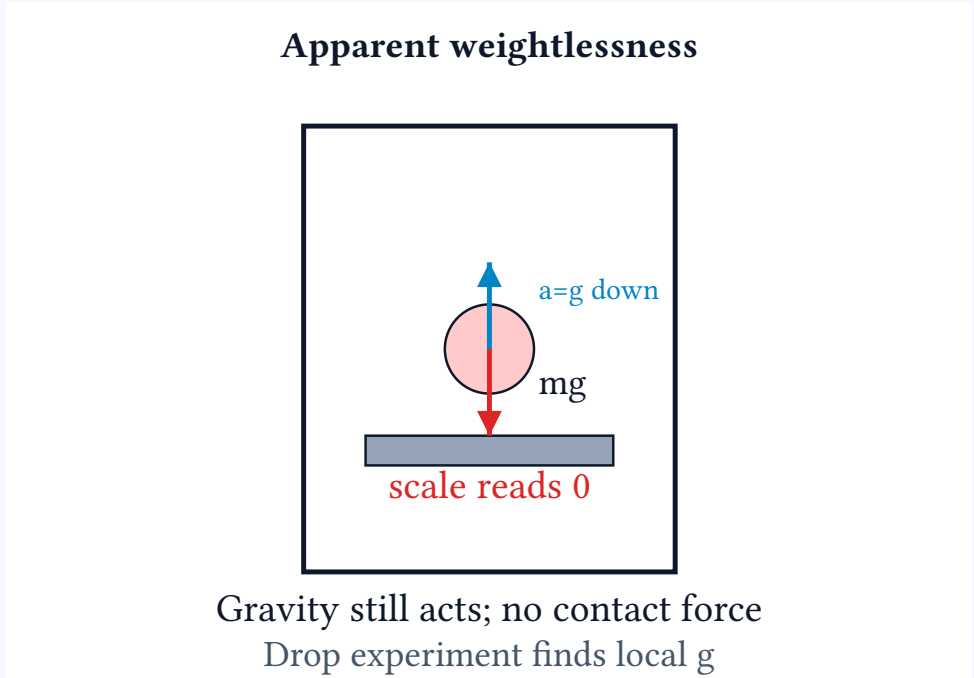


The rover’s ramp force

- The rover mass is 42.0 kg and the ramp is 15 degrees above the horizontal.
- The chosen acceleration up the ramp is 0.500 m/s squared.
- The motor force is 128 N on Earth and 61.4 N on Mars.

Apparent weight

- In apparent weightlessness, gravity still acts.
- The scale reads zero because the person and the scale accelerate together.
- A drop timed in this room can give a local g a little different from 9.81 N/kg.



A 0.800 m drop

- A mass falls 0.800 m from rest in 0.404 s.
- Compute the local field strength from 2 d over t squared.
- Compare your result with 9.81 N/kg, the value these problems use near Earth’s surface.

Weight and a uniform g

- A 70.0 kg geologist stands on Mars, where g is 3.71 N/kg.
- Find the weight on Mars and the weight on Earth.
- Near Earth's surface in these problems, use g = 9.81 N/kg straight down.