Physics 20 full slide deck

Physics 20

Unit A: Motion in one and two dimensions

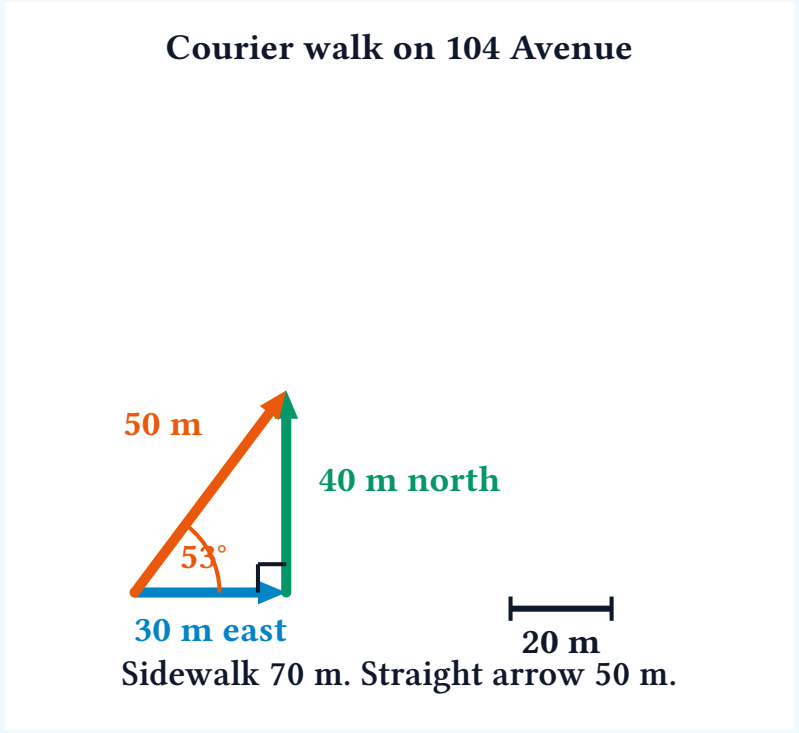
Scalars and vectors

A courier finishes 50 m from the start

- A courier in Edmonton walks 30 m east on 104 Avenue and then 40 m north to a warehouse door.
- The sidewalk path adds to 70 m, while the straight position change is 50 m north of east.

Magnitude and direction

- Pick a doorway as the start. Distance is how far the feet walked. Position is where you are from that doorway.
- A scalar is finished when you write the number and the unit. A vector still needs a direction, such as north of east.
- Displacement is written delta d. It means where you finished minus where you started, with a direction.



Key terms

position

Position is the location of an object relative to a chosen origin, stated with a distance and a direction. (d)

distance

Distance is the length of the path actually travelled, recorded as a magnitude and a unit.

displacement

Displacement is the straight change from the initial position to the final position, with direction included. (delta d)

scalar

A scalar is a quantity fully described by a magnitude and a unit.

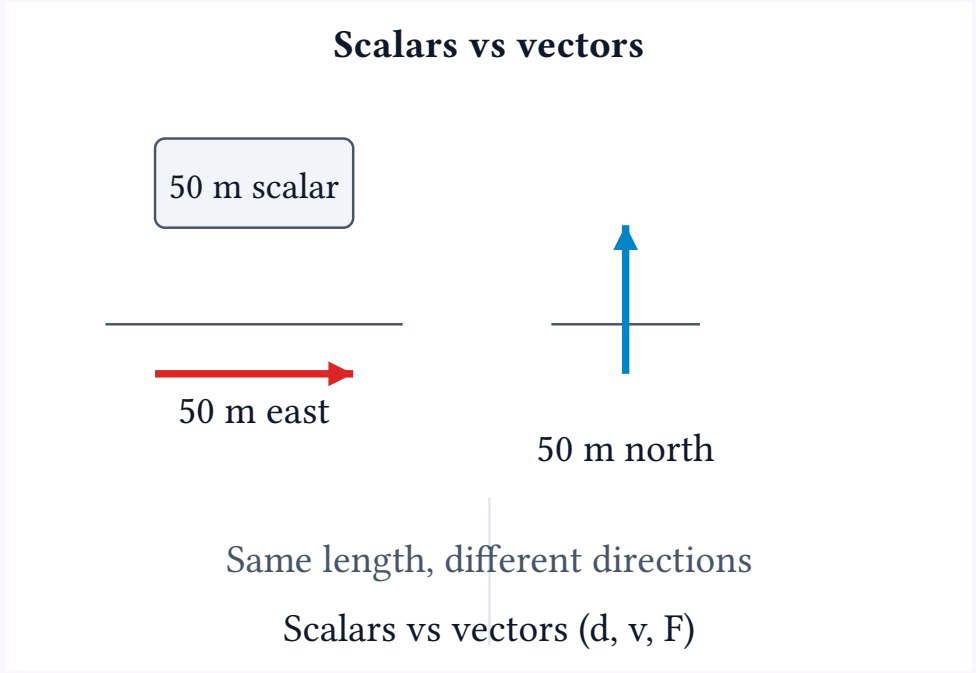
Key terms

vector

A vector is a quantity described by a magnitude, a unit, and a direction.

Scalars and vectors

- Distance, time, and speed are scalars. A number and a unit finish each one.
- Displacement, velocity, acceleration, and force each need a direction beside the number.
- Two 50 m arrows can point different ways. Same length, different vectors.



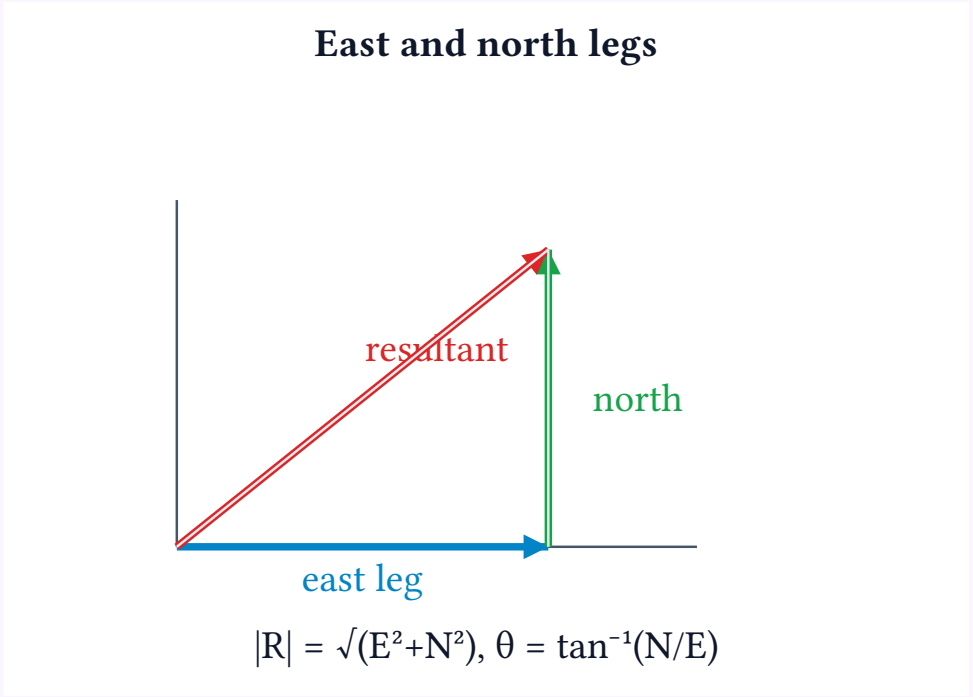
Scalars vs vectors (d, v, F)

A return to the doorway

- The courier later walks back to the original doorway along a 90 m route.
- Distance for the whole outing includes every metre of sidewalk.
- Displacement for the whole outing is 0 m because the final position matches the initial position.

East and north legs make one arrow

- Write the east leg and the north leg first. They stand in for the single arrow.
- Square each leg, add the squares, and take the square root. That length is the straight arrow.
- The angle is the tan inverse of the north leg divided by the east leg.



A drone’s two legs

- A survey drone flies 120 m west and then 50 m south.
- Find the distance and the displacement from the launch pad.
- Give the direction as an angle south of west.

Path and arrow

- A student walks 8.0 m north along a hallway and then 6.0 m east into a lab.
- State the distance and the displacement with direction.
- Name which result is a scalar and which result is a vector.

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Unit A: Motion in one and two dimensions

Velocity and acceleration graphs

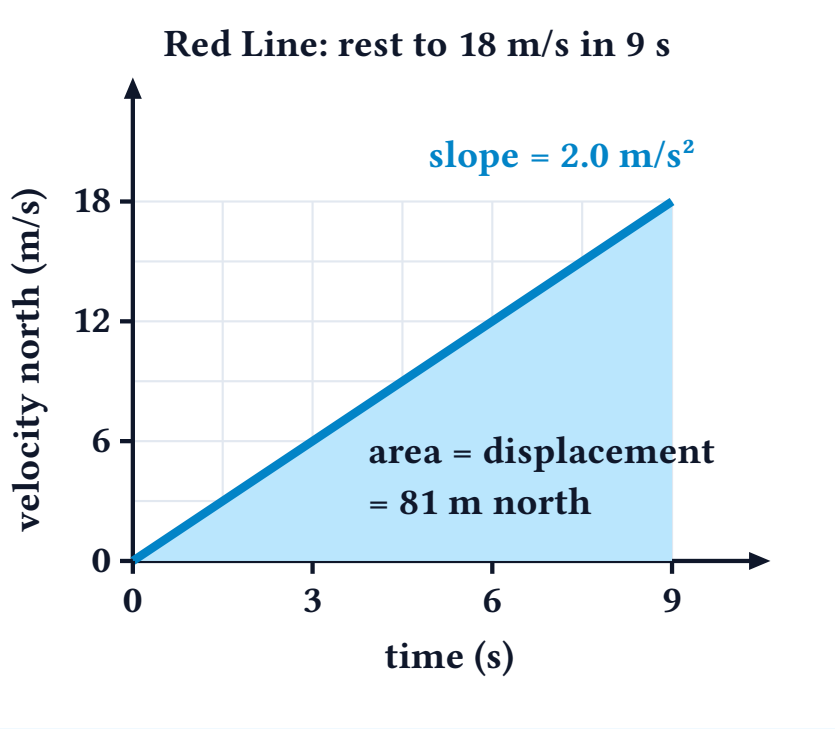
An LRT departure

- A Calgary CTrain on the Red Line leaves Somerset-Bridlewood from rest and reaches 18.0 m/s north in 9.00 s.
- Average velocity uses displacement over elapsed time, and acceleration uses the velocity change over elapsed time.



Rates and graphs

- Delta means final minus initial.
- Velocity v equals delta d divided by delta t. Here d is position and t is time.
- Acceleration a equals delta v divided by delta t.
- Uniform motion keeps the same velocity. Uniformly accelerated motion keeps the same acceleration.



Key terms

velocity

Velocity is displacement divided by elapsed time, and the statement includes the direction of the motion. (v = delta d / delta t)

acceleration

Acceleration is the change in velocity divided by elapsed time, and the statement includes direction. (a = delta v / delta t)

uniform motion

Uniform motion is motion at constant velocity, so equal displacements occur in equal time intervals.

uniformly accelerated motion

Uniformly accelerated motion is motion at constant acceleration, so velocity changes by equal amounts in equal times.

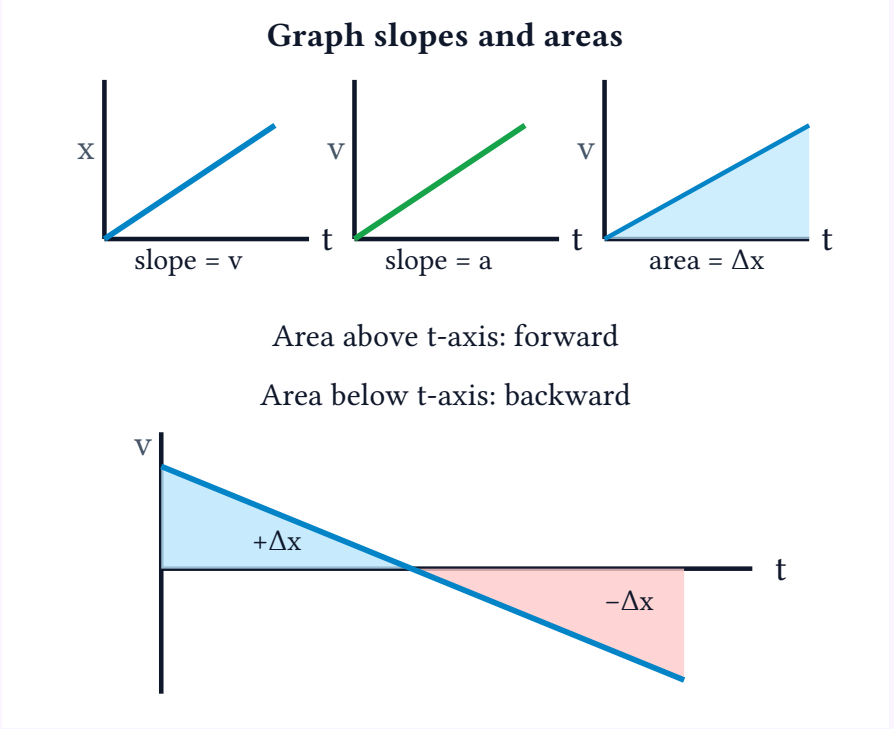
Key terms

delta notation

Delta notation writes a change as the final value of a quantity minus its initial value. $\Delta v = v_{final} - v_{initial} = 18.0\frac{m}{s} - 0\frac{m}{s} = 18.0\frac{m}{s}$. (Δ)

Slope and area of graphs

- The slope of a position time graph is the velocity.
- The slope of a velocity time graph is the acceleration.
- The area under the velocity time line equals the displacement. Area above the time axis is forward. Area below it is backward.

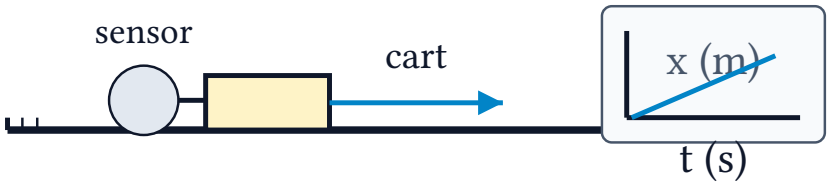


Three equations for constant acceleration

- From rest, $v = 0 + (2.0\ m/s^2)(9.00\ s) = 18\ m/s$ north.
- Displacement is $(1/2)(2.0\ m/s^2)(9.00\ s)^2 = 81\ m$ north.
- Check: $v^2 = 0 + 2(2.0\ m/s^2)(81\ m) = (18\ m/s)^2$.

Cart lab plan

- The lab question is: how do displacement, velocity, acceleration, and time connect for one cart?
- A motion sensor records position together with the clock time.
- Write metres and seconds, keep the digits the timer supports, and write each change as final minus initial.



Cart and motion sensor

Record x and t; use Δ = final − initial

A sensor record of a slowing cart

- The motion sensor shows a cart at 6.00 m/s east, then at 2.00 m/s east after 4.00 s.
- Find the acceleration and the displacement during that interval.
- State the acceleration direction relative to the chosen positive direction.

Formula and graph area

- A lab cart starts from rest and accelerates at 0.800 m/s^2 west for 5.00 s.
- Find the final velocity and the displacement.
- The triangle under the velocity time line has an area equal to the displacement.

Image credits

Bernard Spragg, Calgary Lightrail. C Train, CC0 1.0

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Unit A: Motion in one and two dimensions

Relative motion and projectiles

A kayak pointed north on the Bow

- A kayak near Prince’s Island points north at 2.00 m/s relative to the water while the Bow River current is 1.50 m/s east.
- The shore sees both of those velocities at once, so the two arrows add as vectors.

Projectile components

- The kayak's velocity past the shore equals its velocity through the water plus the water's velocity past the shore.
- A component is the part of the velocity along east or along north.
- Measure the angle from the axis you named, and keep it under 90 degrees.
- Projectile motion keeps a steady horizontal component and a vertical component with acceleration 9.81 m/s^2 downward.

Key terms

relative velocity

Relative velocity is the velocity of one object measured by an observer who may also be moving. In v_AC, A is the object and C is the observer. (v_AC = v_AB + v_BC)

component

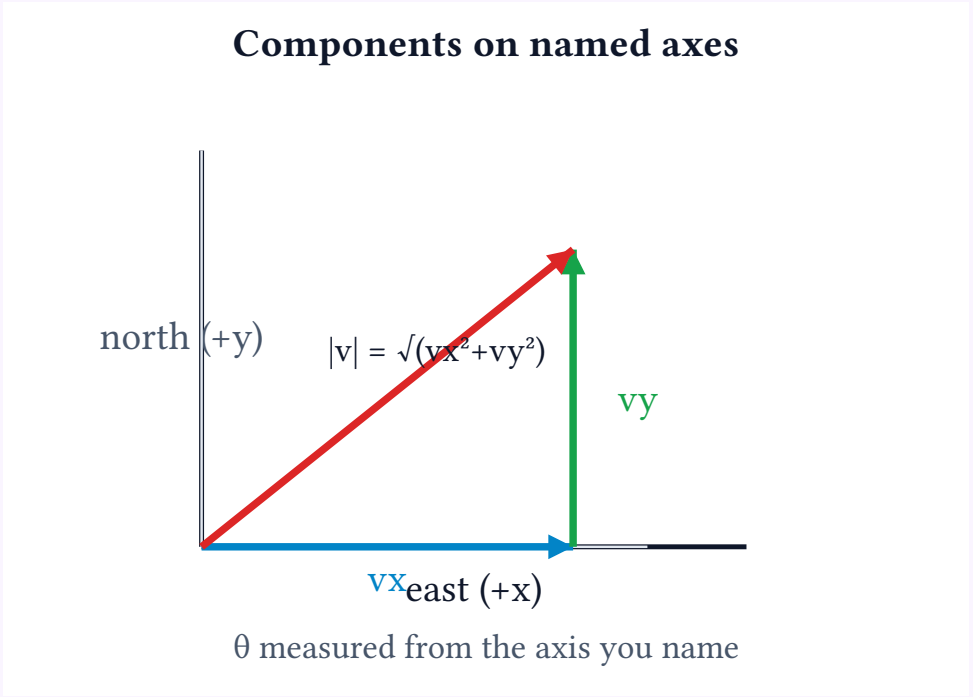
A component is the signed part of a vector along one named axis, such as north or horizontal.

projectile motion

Projectile motion near Earth splits into a steady horizontal velocity and a vertical motion with acceleration 9.81 m/s² downward.

Components along named axes

- Place each velocity on its own axis before you combine the arrows.
- The magnitude is the square root of the sum of the squared components.
- State the angle from the axis you named, such as 37 degrees east of north.



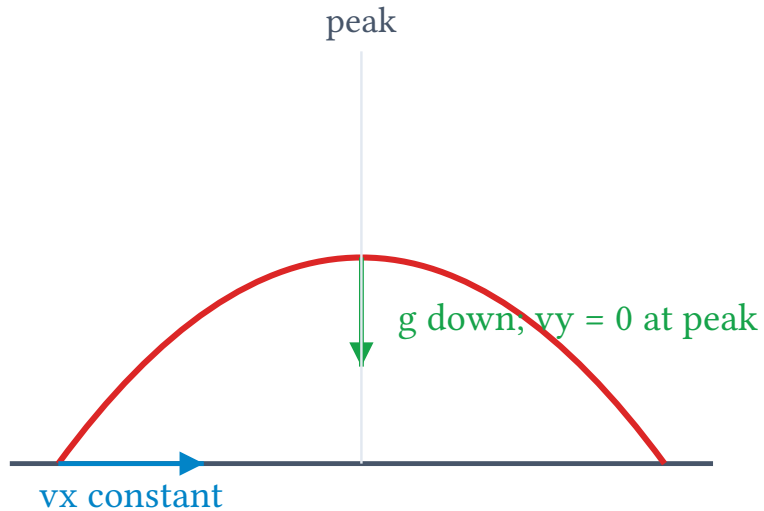
Shore velocity of the Bow kayak

- The kayak component relative to the water is 2.00 m/s north.
- The current component relative to the shore is 1.50 m/s east.
- The shore resultant is 2.50 m/s at 36.9 degrees east of north.

Horizontal rate and vertical free motion

- With air left out, the horizontal velocity stays the same for the whole flight.
- The vertical velocity changes steadily. g is 9.81 m/s squared downward.
- Time of flight comes from the vertical motion, and range is the horizontal velocity times that time.

Horizontal and vertical motion split



g = 9.81 m/s² down sets flight time; range = vx·t

A parcel from a loading dock

- A parcel is tossed horizontally at 5.00 m/s from a dock 1.77 m above the pavement.
- The vertical displacement determines the time of flight.
- The range is the horizontal velocity times that time.

A kick at forty degrees

- A football at McMahon is kicked at 16.0 m/s at 40 degrees above the horizontal.
- Upward is positive, so the vertical acceleration is $-9.81\ \text{m/s}^2$.
- Find the time of flight and the range.

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Unit A: Motion in one and two dimensions

Kinematics in technology and free fall

A Bow pathway commute

- A rider covers 5.40 km along the Bow River pathway from Sunnyside to East Village in 20.0 min.
- Average speed is 5.40 km divided by 20.0 min. People who time a pathway or a bus route use that same division.

Speed and free fall

- Average speed uses total distance over elapsed time and stays a scalar.
- In a vacuum tube, a heavy object and a light object both speed up at 9.81 m/s squared downward.
- Builders test a runway length, a merge lane, or a traffic light time on paper before they pour concrete.

Key terms

average speed

Average speed is the total distance travelled divided by the elapsed time, reported as a magnitude with a unit. (speed = distance / time)

free fall

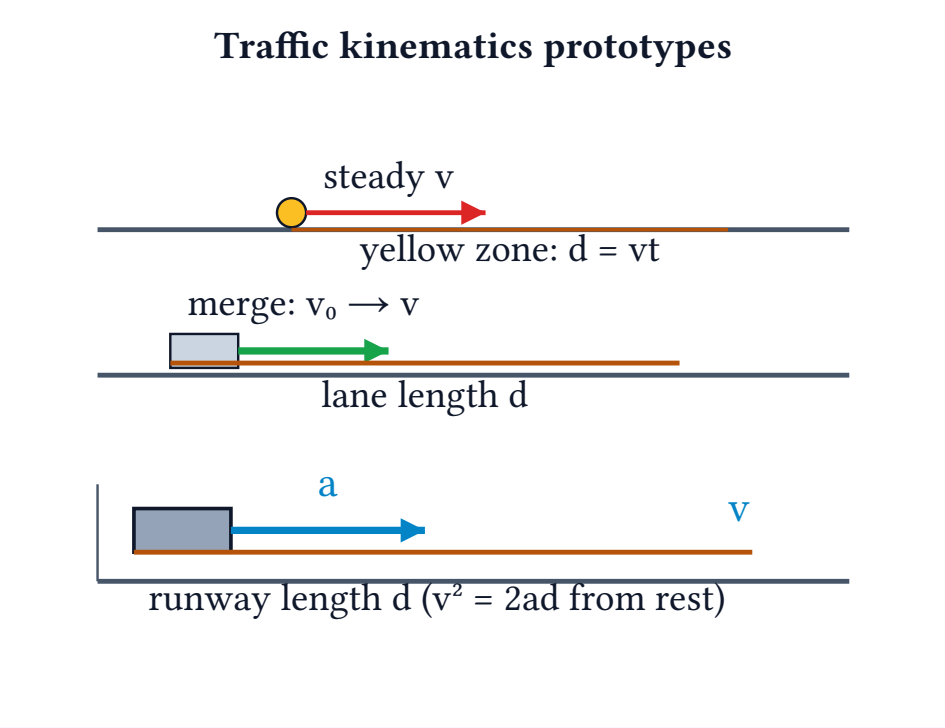
Free fall is motion under gravity alone in the vacuum model, with acceleration 9.81 m/s² downward near Earth.

prototype

A prototype is an early working version of a design, used to test whether the kinematics meet the plan.

Motion in traffic

- During the takeoff roll, the speed up connects the liftoff speed to how long that roll lasts.
- From rest, the runway length comes from v squared = 2 a d.
- Merging lane length and yellow light timing use the same kinematics with different knowns.



A 540 m prototype runway

- The trainer reaches 54.0 m/s from rest at 2.70 m/s².
- Runway length: (54.0 m/s)² / (2 × 2.70 m/s²) = 540 m.
- Roll time: 54.0 m/s / 2.70 m/s² = 20.0 s.

A shared lunar landing

- In vacuum a hammer and a feather share one free fall acceleration.
- The shared landing revised the older idea that a heavier object falls faster.
- People who design roads and runways use these same motion rules, and cart work stays inside a marked zone.



A vacuum tube in the classroom

- A steel nut and a feather drop from rest through 1.23 m in a vacuum tube.
- Free fall near Earth uses $g = 9.81\ \mathrm{m/s^2}$ downward for both objects.
- Both objects reach the bottom together.

A yellow light and a marked zone

- A prototype signal on Gateway Boulevard serves cars in uniform motion at 14.0 m/s.
- The intersection distance is 42.0 m.
- Find the yellow light time. If the cart setup differs from the approved procedure, stop and call the teacher.

Image credits

NASA, Apollo 15 F&H, public domain

Physics 20

Unit B: Forces and gravitation

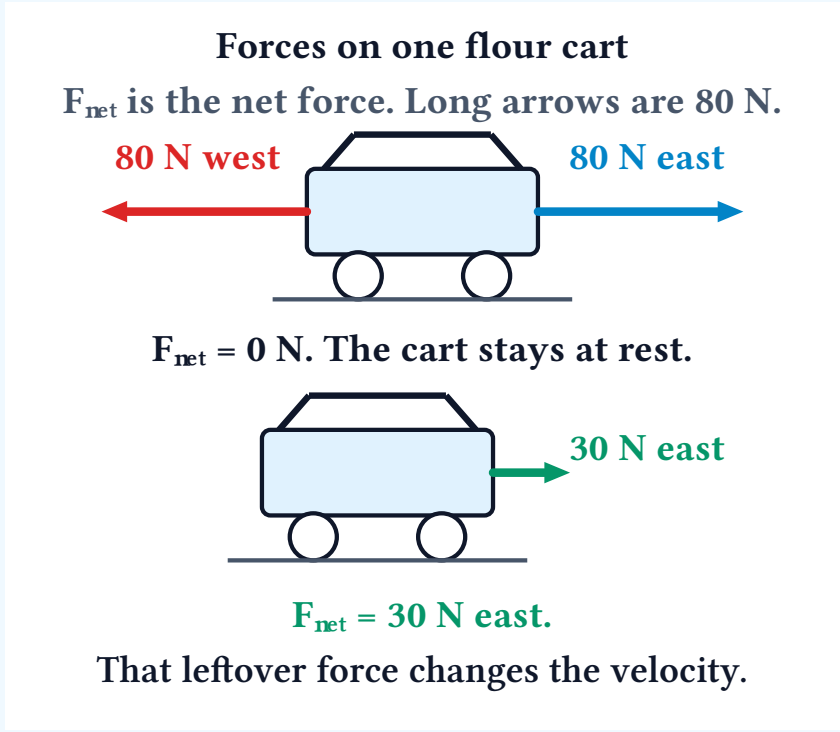
Net force and Newton's first law

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

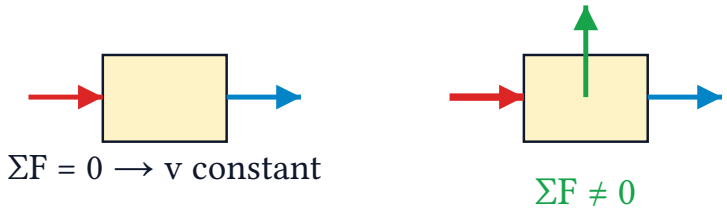
Newton's first law says an object stays at rest or in uniform motion when the net force is zero.

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

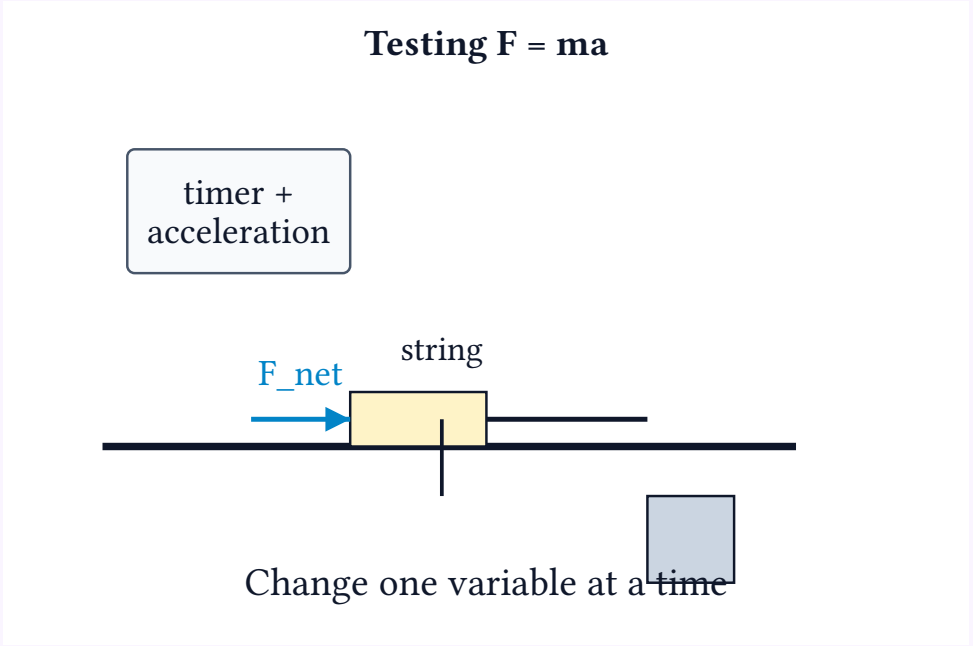
Resultant changes velocity when |ΣF| > 0

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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Unit B: Forces and gravitation

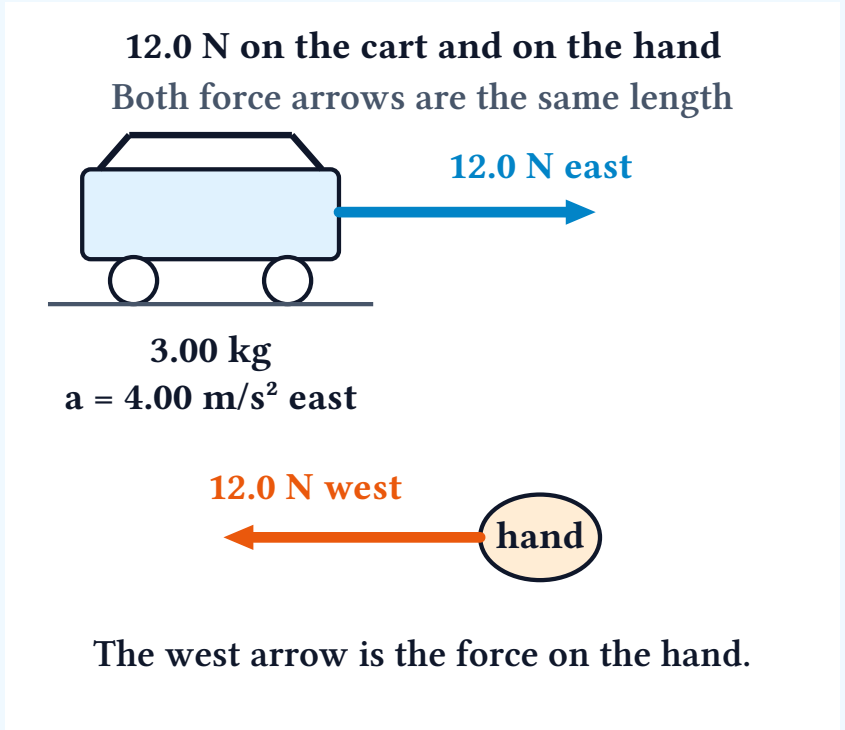
Newton’s second and third laws

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

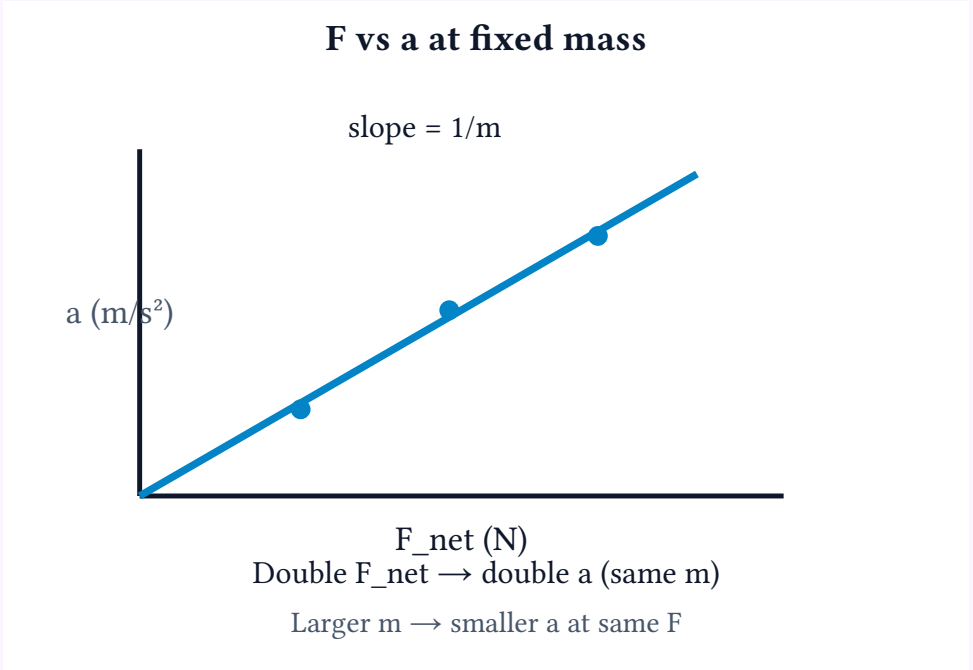
A free body diagram shows only the forces on the chosen object, drawn as arrows on a simple outline.

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.

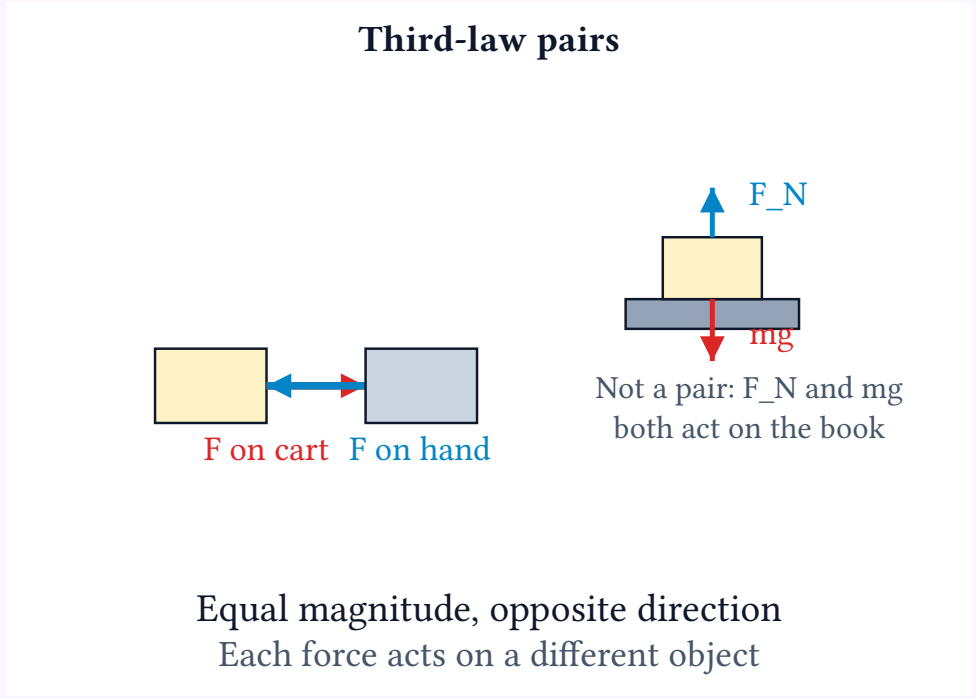


Three ways to state 4.00 m/s squared

- 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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Unit B: Forces and gravitation

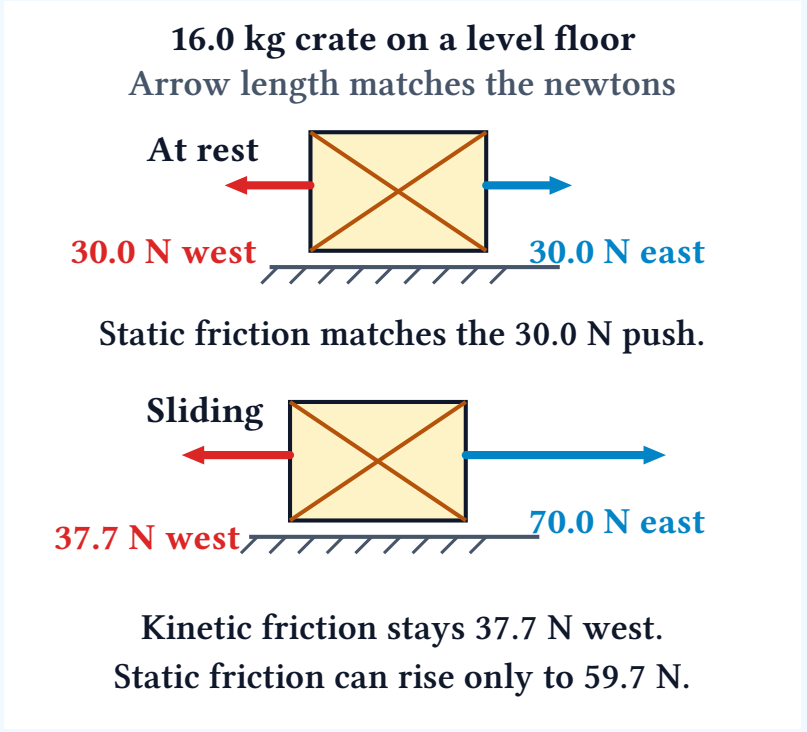
Friction and vector forces

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

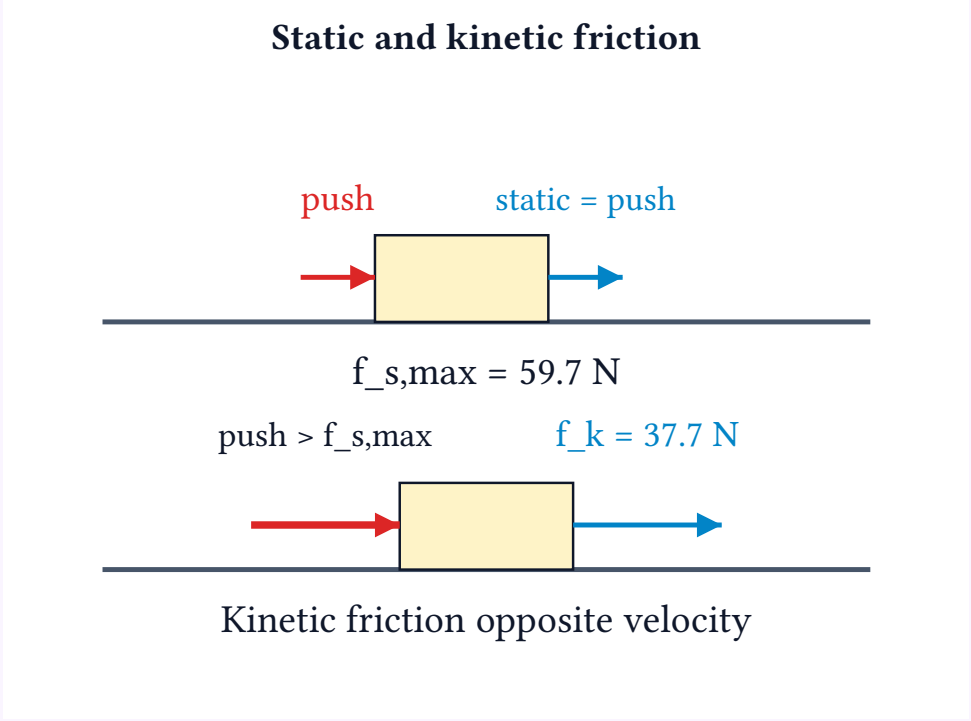
The normal force is the support force a surface exerts perpendicular to the surface. (N)

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.

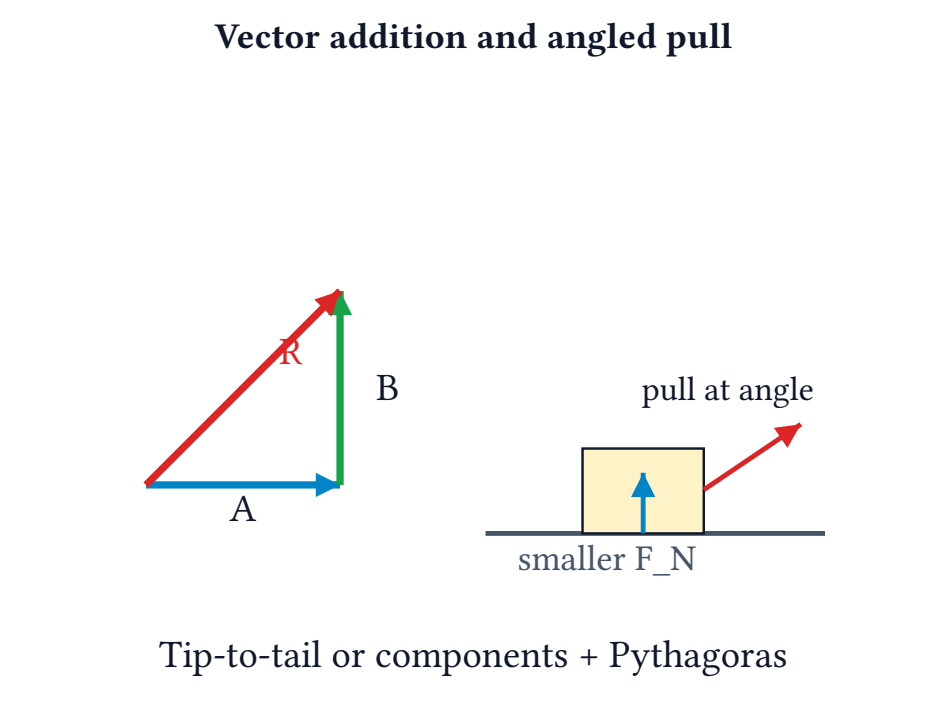


Acceleration once the crate slides

- 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.

Physics 20

Unit B: Forces and gravitation

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

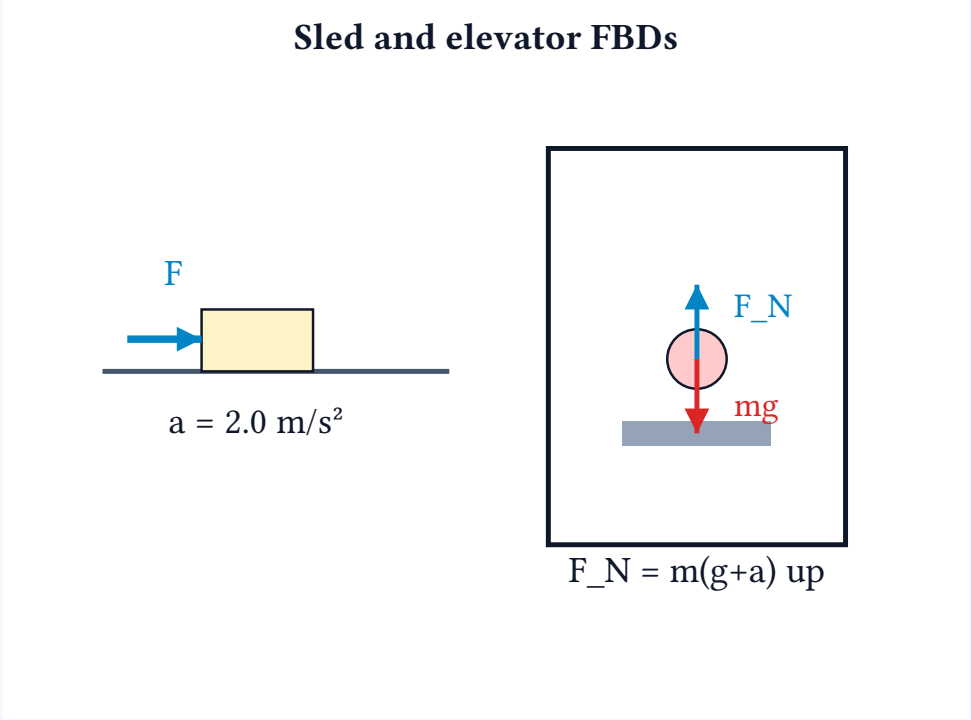
The parallel component of weight is m g sin theta, directed down the incline. Here m is mass, g is 9.81 m/s squared downward, and theta is the angle from the horizontal. (m g sin theta)

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.

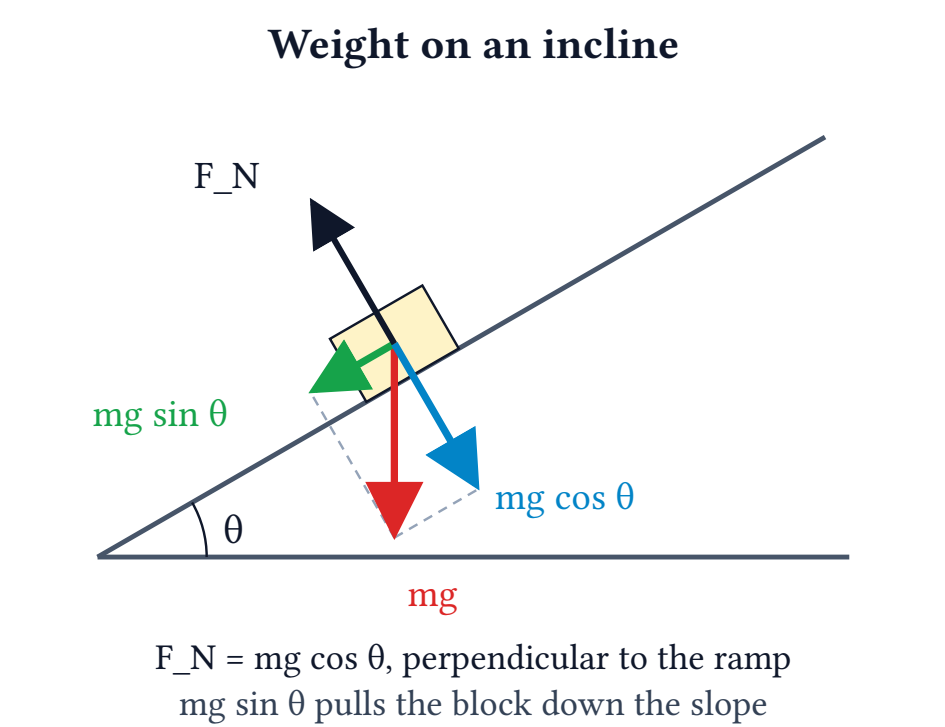


A 30.0 degree cart

- 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.

Physics 20

Unit B: Forces and gravitation

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

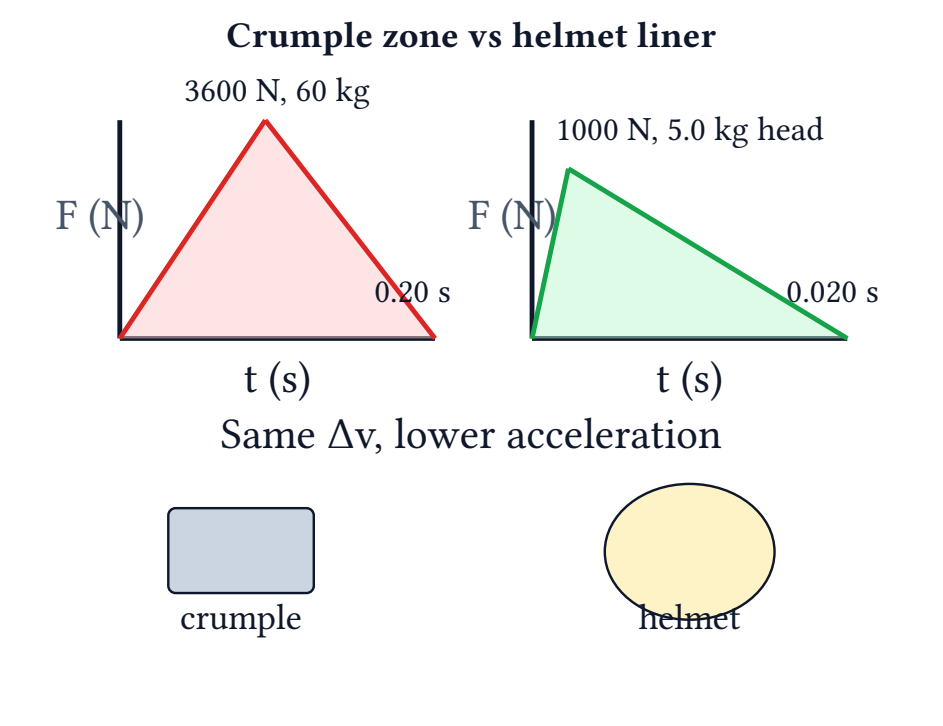
A buffalo jump is a coordinated cliff drive technology that supplied a community harvest of bison.

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.



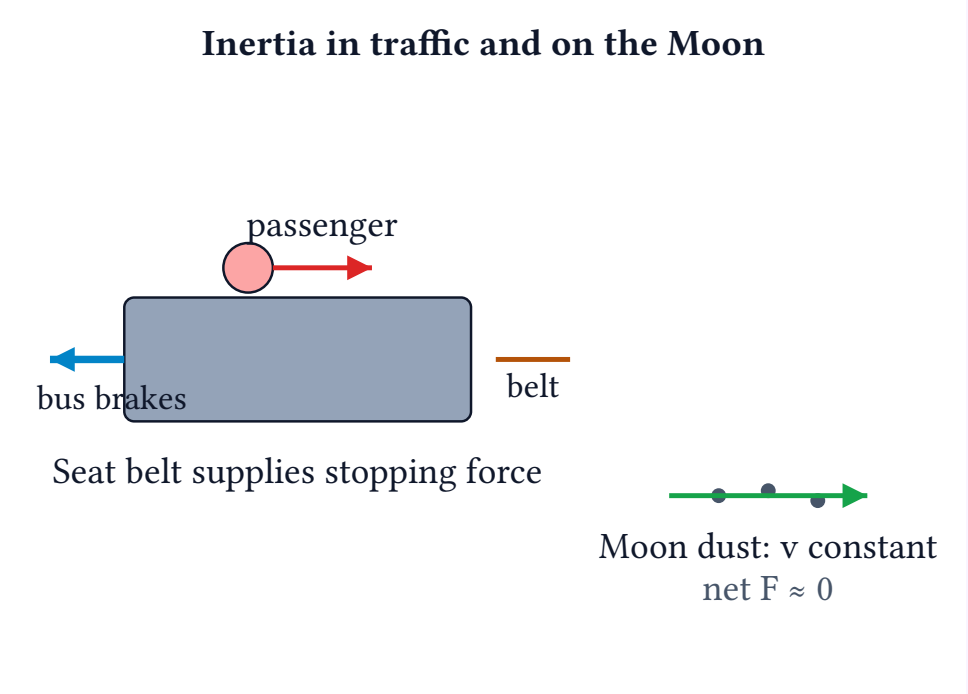
Head Smashed In as planned technology

- 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

Physics 20

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

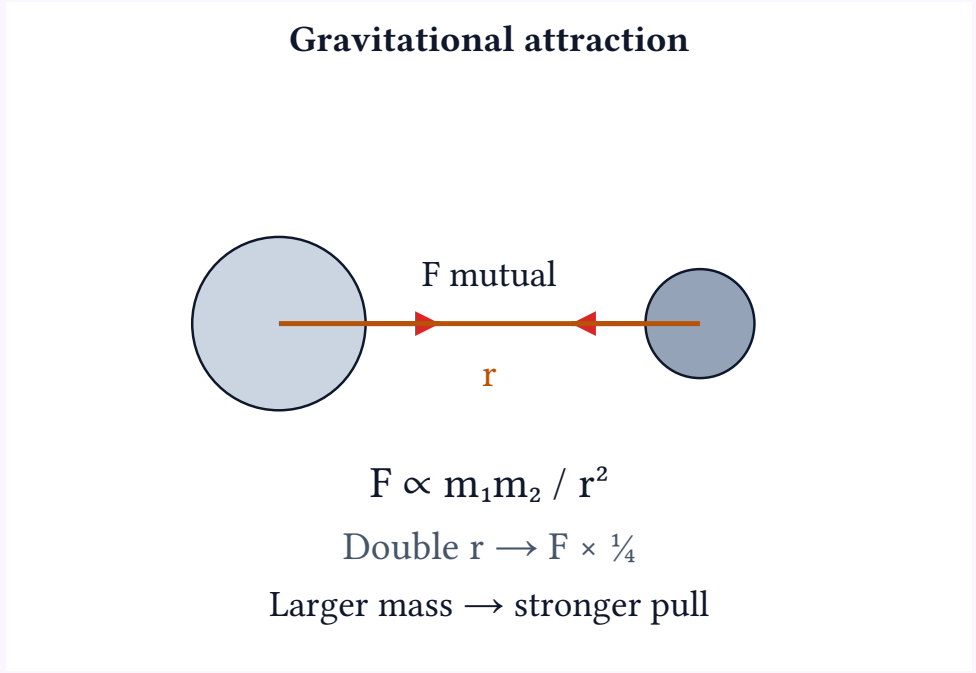
Universal gravitation is the law that every pair of masses attracts with F = G m1 m2 / r squared. ($F = G\ m1\ m2 / r^2$)

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

Physics 20

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

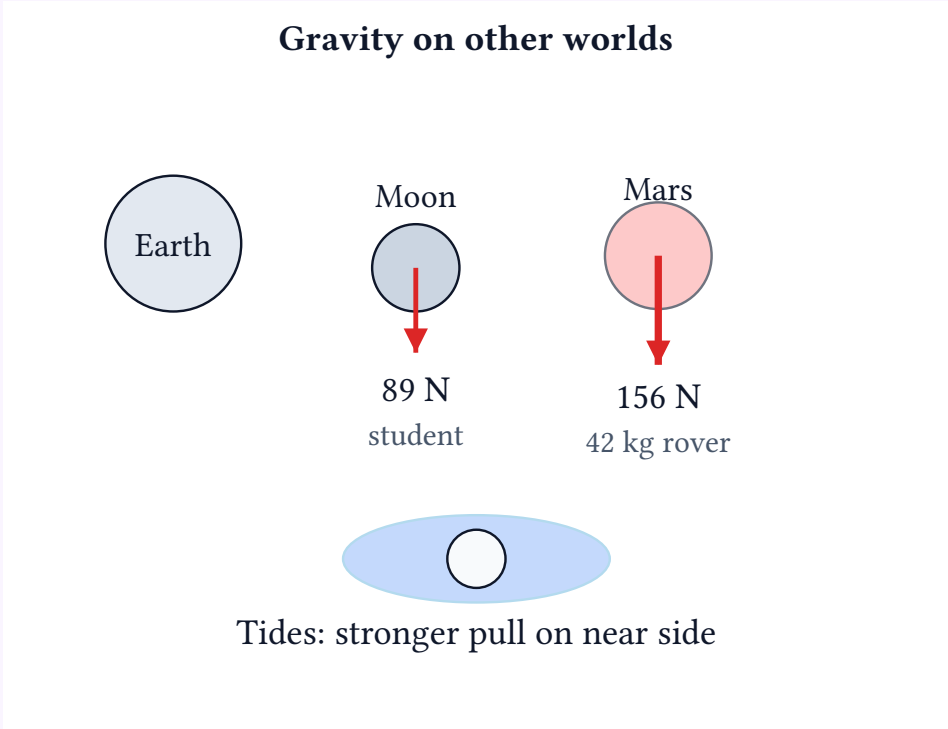
Weight is the gravitational force on an object, equal to mass times the local field strength. ($F_g = m\ g$)

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.

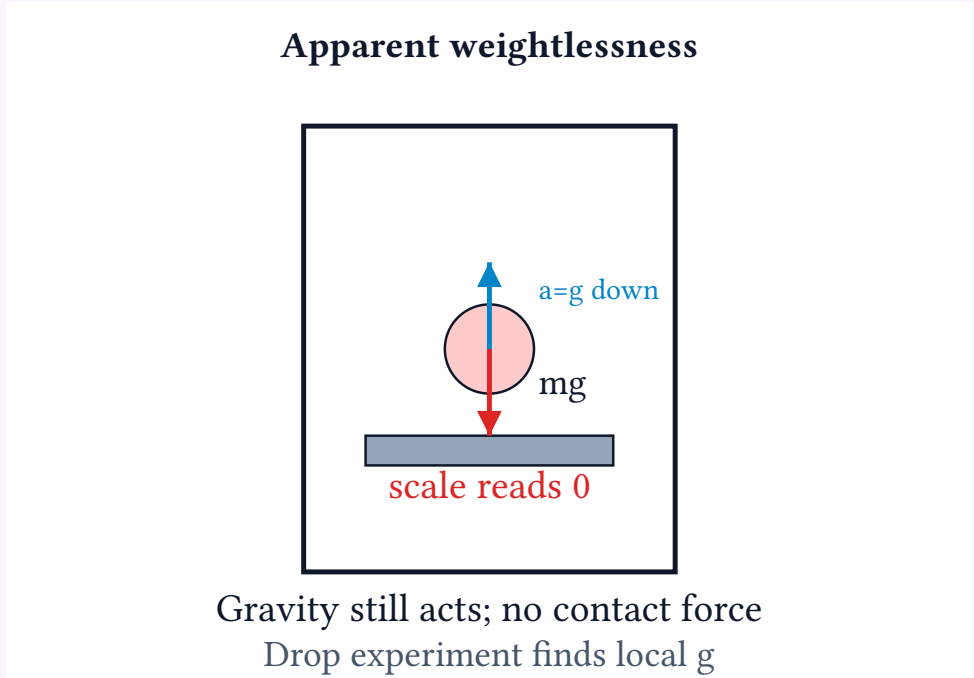


The rover’s ramp force

- 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.

Physics 20

Unit C: Circular motion and energy

Describing circular motion

A teacup seat holds a steady speed

- A midway teacup seat travels a horizontal circle of radius 4.50 m and finishes one full turn every 3.60 s.
- The speed stays steady while the velocity arrow swings through every compass direction around the pole.

Period and frequency

- Uniform circular motion is two dimensional motion with constant speed and a changing direction.
- Radius r, period T, and frequency f are the measurements. Frequency f equals 1 divided by T.
- Speed v equals 2 pi r / T, which is also 2 pi r f.
- Centripetal acceleration a equals v squared over r and points toward the centre.

Key terms

uniform circular motion

Uniform circular motion is two dimensional motion with constant speed and a changing direction.

centripetal acceleration

Centripetal acceleration has magnitude v squared over r and points toward the centre of the circle. ($a = v^2/r$)

period

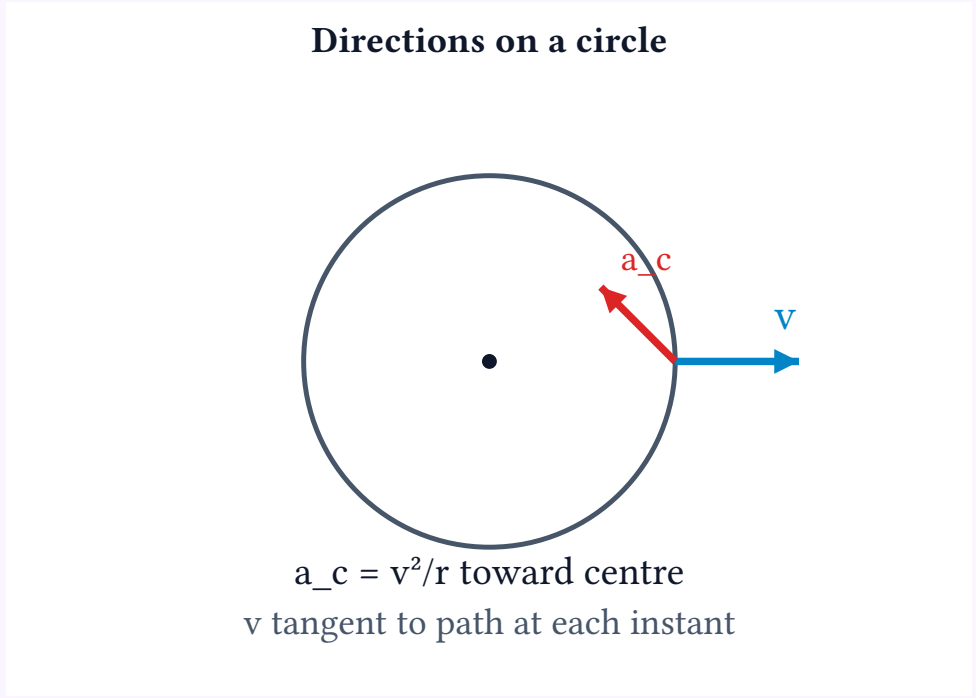
Period is the time for one full cycle, measured in seconds per cycle. (T)

frequency

Frequency is the number of cycles in one second and equals the reciprocal of the period. ($f = 1/T$)

Velocity and acceleration directions

- At each instant the velocity points along the tangent to the circle.
- Centripetal acceleration points toward the centre and has magnitude v squared over r.
- A larger radius at the same period produces a larger speed.

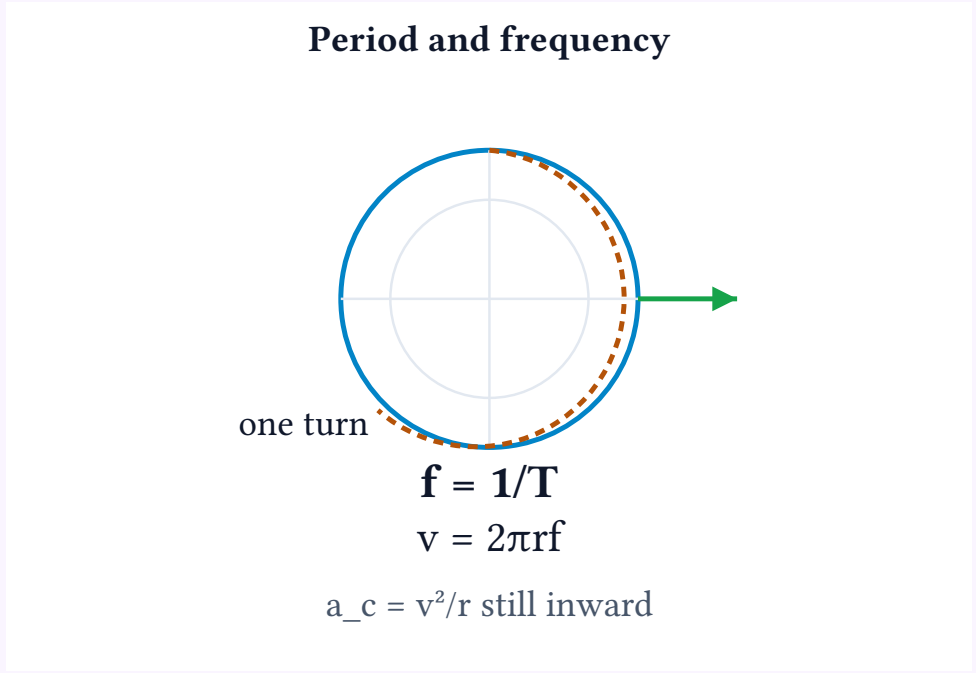


A skater’s lap on the outdoor rink

- The skater’s circle has radius 8.00 m and period 5.00 s.
- Speed = 2 × 3.14 × 8.00 m / 5.00 s = 10.1 m/s.
- With the unrounded speed, $v^2 / r = 12.6\ m/s^2$ toward the centre.

Frequency is one divided by the period

- Frequency f equals 1 divided by the period T.
- The speed can be written as 2 pi r f when the data arrive as turns each second.
- Centripetal acceleration still uses v squared over r and points toward the centre.



A go kart lap

- A go kart follows a circle of radius 25.0 m with a period of 14.0 s.
- Find the speed, the frequency, and the centripetal acceleration.
- State the direction of the acceleration.

A runner’s circular track

- A runner follows a circular track of radius 30.0 m and completes one lap in 18.0 s.
- Find the speed, the frequency, and the centripetal acceleration.
- Include the unit and the direction the acceleration requires.

Physics 20

Unit C: Circular motion and energy

Forces in circles

A car on a curve

- A 1200 kg car holds 16.0 m/s through a horizontal curve of radius 45.0 m.
- Friction toward the centre supplies the net force that keeps changing the car’s direction.

The inward net force has a name

- In m v squared over r, m is the mass, v is the speed, and r is the radius.
- Centripetal force is the net force toward the centre, and its size is m v squared over r.
- Banking tilts the normal force so a component points toward the centre of a curve.
- A centrifuge, a carnival circle, and a potter’s wheel each need that inward net force.

Key terms

centripetal force

Centripetal force is the net force toward the centre of the circle, with magnitude m v squared over r. ($F = m\,v^2/r$)

banking

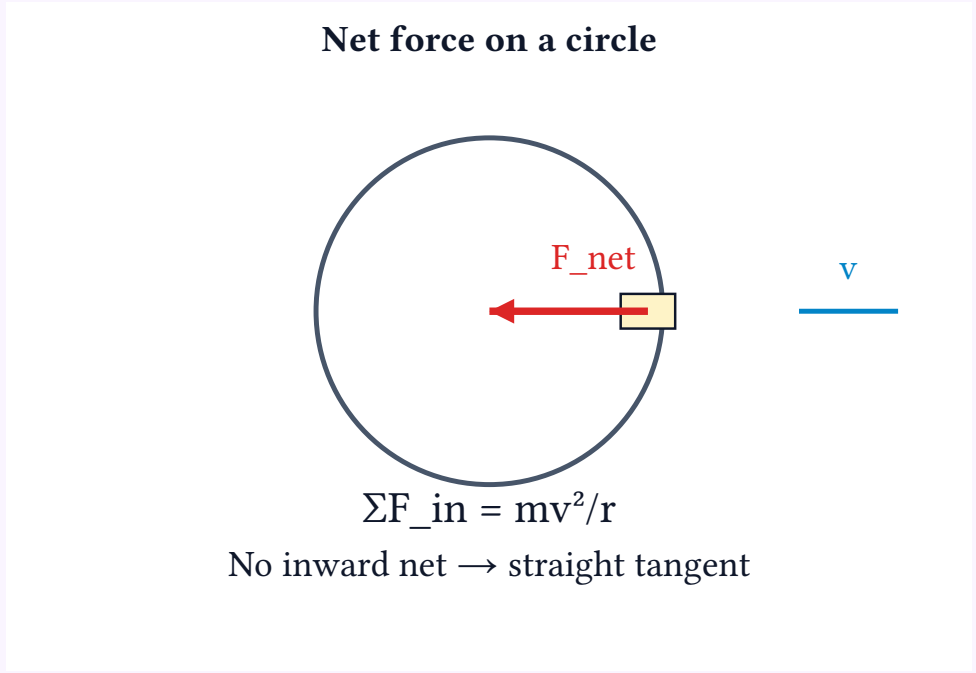
Banking tilts a roadway so the normal force has a horizontal component toward the centre of the curve.

centrifuge

A centrifuge spins samples in a circle so a large inward net force separates materials by how they respond to that force.

Newton’s laws on the circle

- The net force toward the centre equals m v squared over r.
- A zero inward net force leaves the velocity on a straight tangent.
- The inward force keeps changing the direction while it acts.

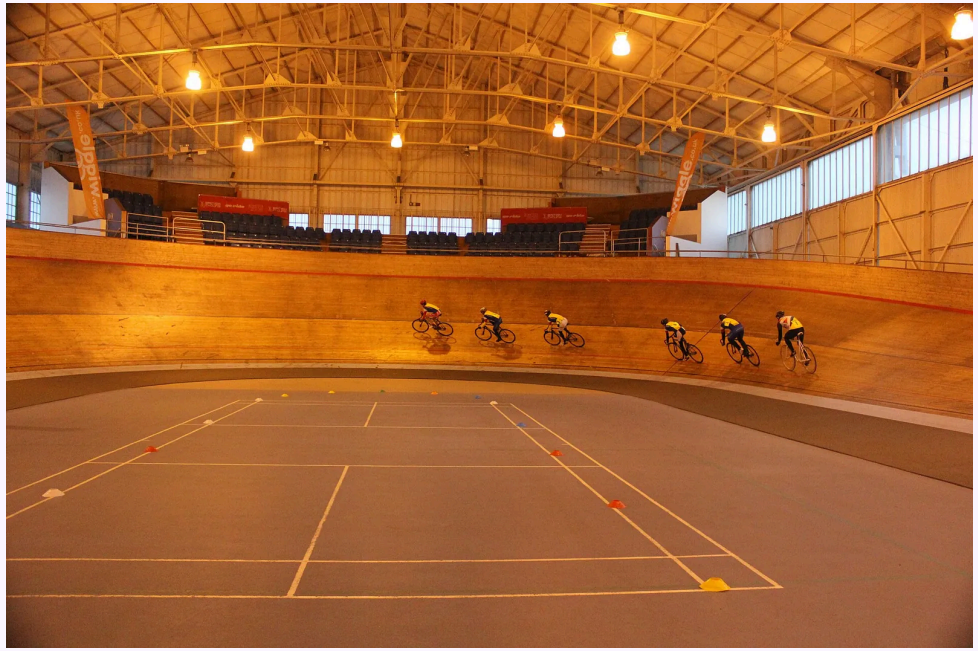


Friction on the level curve

- The car’s mass is 1200 kg, its speed is 16.0 m/s, and the radius is 45.0 m.
- $F = (1200\ \text{kg})(16.0\ \text{m/s})^2 / 45.0\ \text{m}$.
- That force is 6.83×10^3 N toward the centre.

Circular motion technologies

- A stopper lab relates orbital speed, radius, acceleration, and centripetal force.
- Banking uses an acute angle from the horizontal so the normal force can point partly inward.
- A centrifuge, a vertical carnival loop, and a potter’s wheel use the same inward net force.



Top of a vertical circle

- A 0.500 kg bucket on a 0.800 m rope moves at 4.00 m/s at the top of a vertical circle.
- At the top, tension and weight both point toward the centre.
- Their sum equals m v squared over r.

A clinical centrifuge

- A centrifuge holds a 0.00800 kg sample at radius 0.120 m and frequency 40.0 Hz.
- Find the speed and the centripetal force on the sample.
- Name the real object that supplies the inward force.

Image credits

Paul W, Calshot velodrome, CC BY-SA 4.0

Physics 20

Unit C: Circular motion and energy

Orbits and Kepler's laws

A moonlet circles a giant

- A small satellite orbits a planet at radius 4.20 times 10 to the seventh metres with speed 3.50 times 10 to the third m/s.
- The gravitational pull toward the planet is the centripetal force, so the planet’s mass can be read from the orbit.



Orbits and Kepler’s laws

- M is the central mass, v is the orbital speed, r is the orbit radius, G is the gravity constant, and T is the period.
- For a circular orbit, the central mass equals speed squared times radius, divided by G.
- The same mass is M = 4 pi squared times r cubed, divided by G T squared.
- Kepler’s third law says the period squared grows with the radius cubed. That pattern pointed toward inverse square gravity.
- A satellite that orbits once each day stays over one longitude.

Key terms

satellite

A satellite is an object in orbit around a larger central body, held by the gravitational force toward that body.

geosynchronous orbit

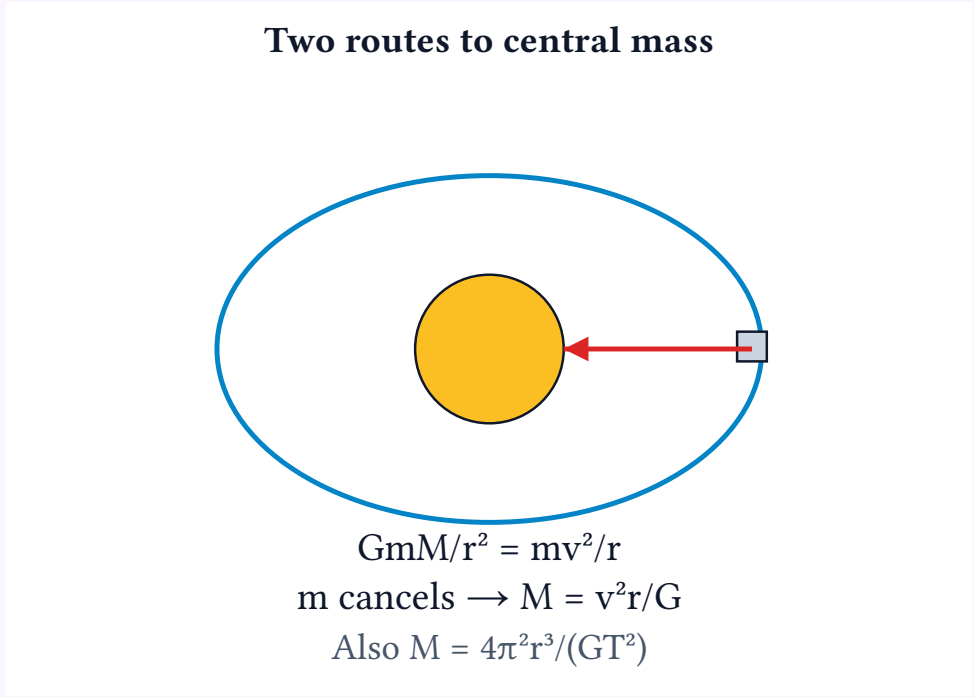
A geosynchronous orbit has a period that matches Earth's rotation period, so the satellite stays over the same longitude and can serve communication. (T = 8.64e4 s)

Kepler's laws

Kepler's laws describe orbits, and the third law says the square of the period is proportional to the cube of the average radius. (T^2 proportional to r^3)

Two routes to the central mass

- Set G M m over r squared equal to m v squared over r.
- The satellite mass m cancels, leaving $M = v^2 r / G$.
- The period form $M = 4 \pi^2 r^3 / (G T^2)$ matches that result.

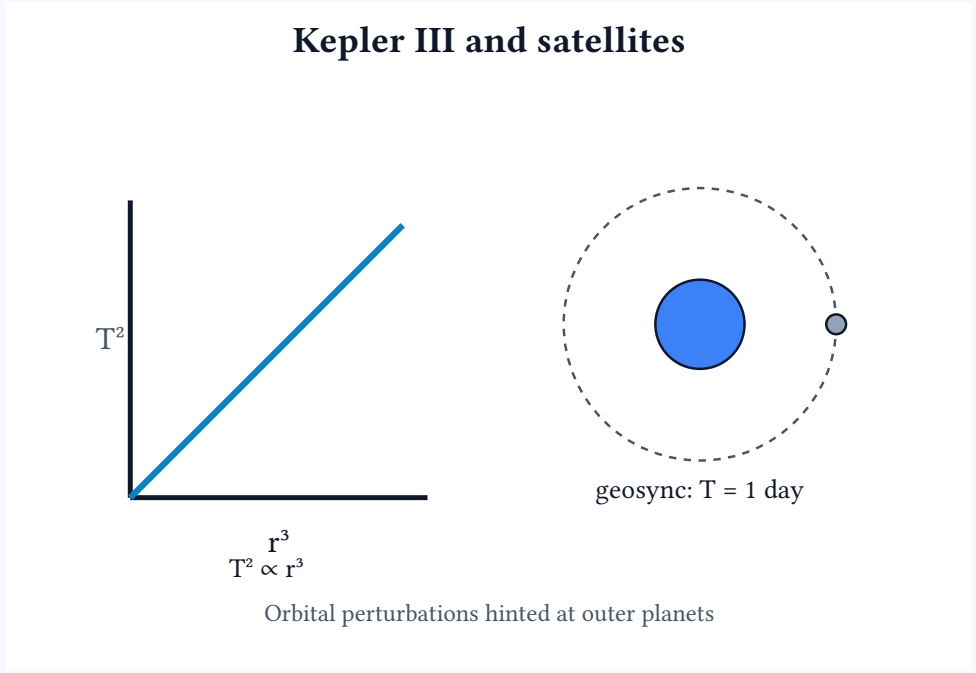


Central mass from a moonlet orbit

- Use v = 3.50 times 10 to the third m/s and r = 4.20 times 10 to the seventh metres.
- M = $(3.50\times10^{3})^{2} \times (4.20\times10^{7}) / 6.67\text{e-}11$.
- The central mass is 7.71×10^{24} kg, and the period form agrees.

Kepler’s third law and satellites

- Kepler’s third law says T squared is proportional to r cubed.
- That proportion led toward Newton’s inverse square law, and orbital perturbations later pointed to outer planets.
- A geosynchronous satellite orbits once each day, so a dish on the ground can keep pointing at it.



An outer moon’s period

- An inner moon has radius 2.00 times 10 to the eighth metres and period 2.40 times 10 to the fifth seconds.
- An outer moon of the same planet has four times the radius.
- Use Kepler’s third law to find the outer period.

Radius of a geosynchronous satellite

- Earth’s mass is 5.97 times 10 to the 24th kilograms and the rotation period used here is 8.64 times 10 to the fourth seconds.
- Find the geosynchronous radius from M = 4 pi² r³ / (G T²).
- State the communication job of that orbit.

Image credits

NASA/JPL/University of Arizona, PIA02879 - A New Year for Jupiter and Io, public domain

Physics 20

Unit C: Circular motion and energy

Mechanical energy

A skateboarder drops in from 3.20 m

- A 48.0 kg skateboarder starts from rest at a height of 3.20 m on a quarter pipe.
- At the bottom the height is zero on the chosen scale, and the speed is 7.92 m/s.



Conservation of mechanical energy

- Em = Ek + Ep, with Em the mechanical energy, Ek the kinetic energy, and Ep the gravitational potential energy.
- Ek = (1/2) m v^2, where m is the mass and v is the speed.
- Ep = m g h, where h is the height and g is 9.81 m/s^2 downward.
- When the object keeps that energy to itself, Ek plus Ep stays the same number.

Key terms

mechanical energy

Mechanical energy is the sum of kinetic energy and gravitational potential energy for the object in the model. (Em = Ek + Ep)

kinetic energy

Kinetic energy is the energy of motion, equal to one half the mass times the speed squared. (Ek = (1/2) m v^2)

gravitational potential energy

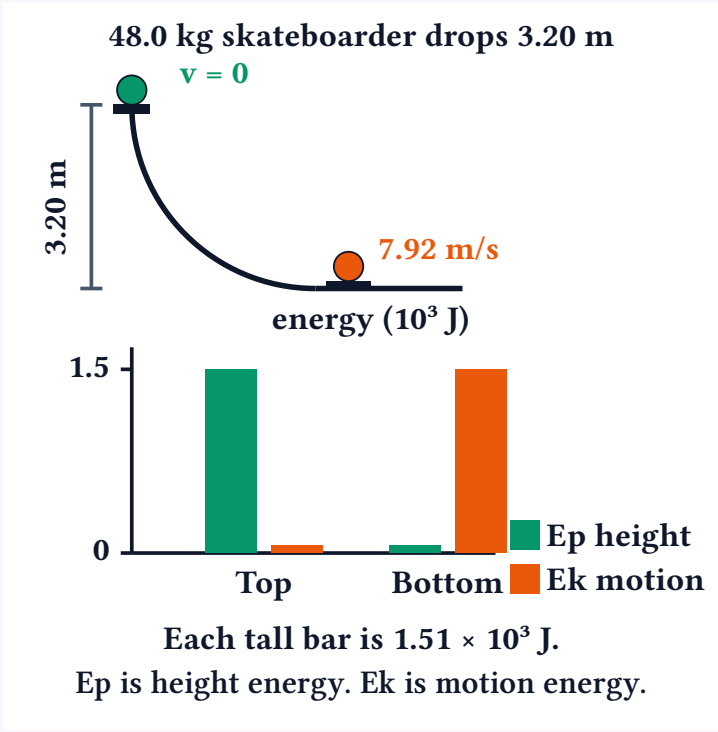
Gravitational potential energy near Earth is mass times g times height, with height measured from a chosen zero. (Ep = m g h)

isolated system

An isolated system keeps its mechanical energy constant because that energy stays inside the chosen boundary.

Energy bar charts

- At the top of a hill, gravitational potential energy holds the mechanical energy.
- At the bottom, the energy is kinetic, and the total matches the potential energy from the top.
- The bar chart keeps Ep and Ek side by side so the trade is visible.



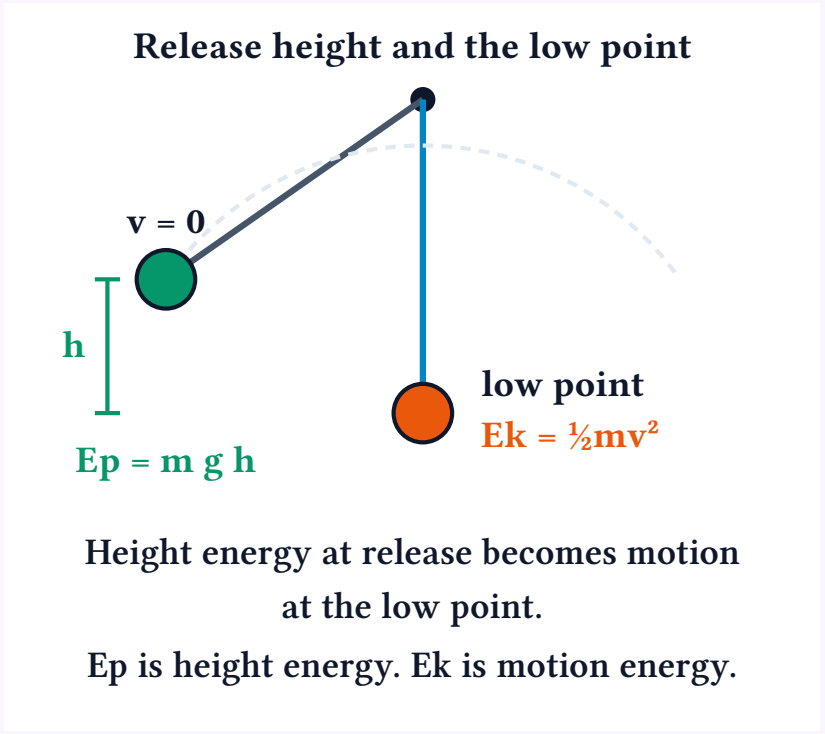
Each tall bar is 1.51 × 10³ J.
Ep is height energy. Ek is motion energy.

A ski hill checked two ways

- A 62.0 kg skier starts from rest at a height of 8.50 m. The slope length is 25.0 m.
- From the height, speed = square root of 2 × 9.81 × 8.50 = 12.9 m/s.
- The 25.0 m slope gives the same 12.9 m/s.

A pendulum lab and Joule’s paddles

- A pendulum or a rolling cart can test whether the energy total stays the same when friction is tiny.
- Release height sets Ep, and the low point converts that store into Ek.
- Joule’s falling weights and paddles linked mechanical work with thermal energy and named the joule.



Pendulum speed at the low point

- A 0.200 kg bob is released from rest 0.150 m above the low point.
- Ep at release equals m g h.
- At the low point the height energy has become kinetic energy, one half m v squared.

A toboggan hill

- A 35.0 kg toboggan starts from rest at a height of 4.80 m.
- Find Ep at the top and the speed at the bottom.
- State the quantity that stays the same from the top of the hill to the bottom.

Image credits

Tiia Monto, Skateboard ramp, CC BY-SA 3.0

Physics 20

Unit C: Circular motion and energy

Work and power

A sled rope at 25 degrees

- A student pulls a sled with 48.0 N at 25 degrees above the horizontal through a displacement of 6.00 m.
- That pull transfers 261 J, and the same job done in 8.00 s has a power of 32.6 W.

Work and power

- W is the work, F is the force, d is the displacement, and theta is the angle between them.
- Work equals F d cos theta. P is the power, equal to W divided by delta t, and delta means final minus initial.
- W_{net} means the net work. It equals delta Ek, the change in kinetic energy.

Key terms

work

Work is the energy transferred by a force along a displacement, equal to F d cos theta. (W = F d cos theta)

power

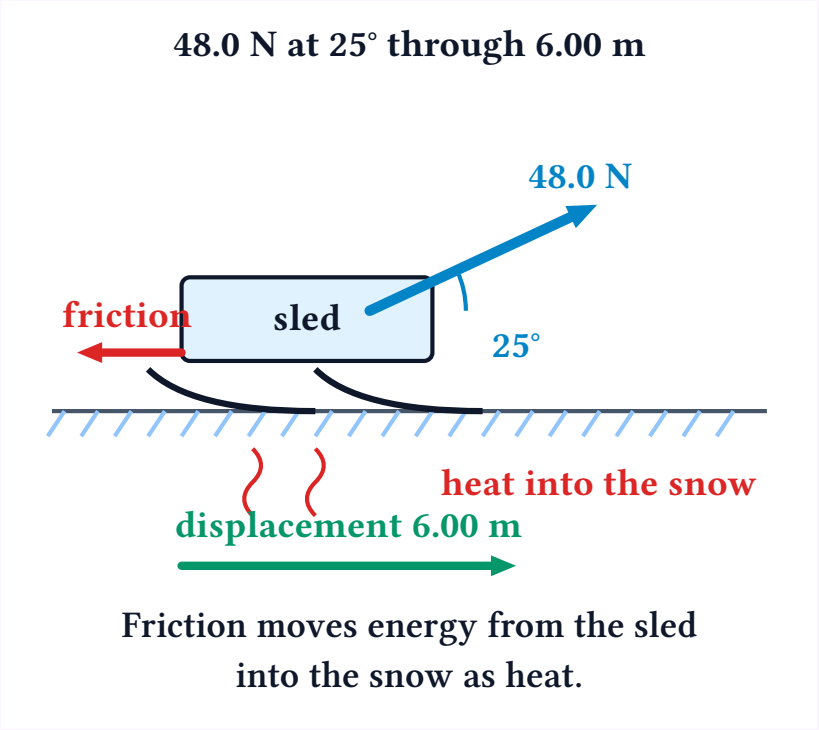
Power is the rate of doing work, equal to work divided by the elapsed time. (P = W / delta t)

work energy theorem

The work energy theorem says the net work on an object equals its change in kinetic energy. (W_{net} = delta Ek)

An open system warms the snow

- A free body diagram organizes the forces before work is calculated.
- An open system exchanges energy with the surroundings, so mechanical energy inside can change.
- Friction transfers energy into the snow and the runners as thermal energy.



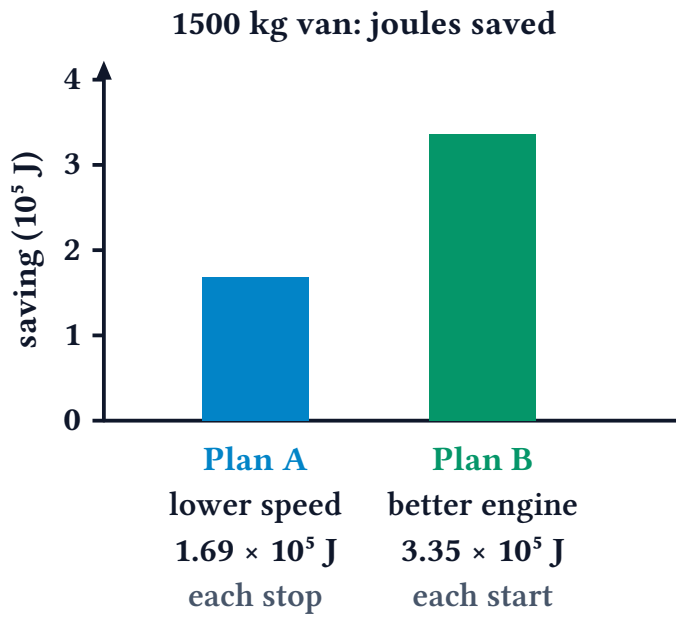
Friction moves energy from the sled into the snow as heat.

Joules and watts for the sled pull

- The pull is 48.0 N through 6.00 m at 25 degrees from the displacement.
- W = (48.0 N)(6.00 m)(cos 25 degrees) = 261 J.
- Power = 261 J / 8.00 s = 32.6 W.

Net work and kinetic energy

- W_{net}, the net work, equals delta Ek, the change in kinetic energy.
- A lower speed limit and a more efficient engine save different joules on a 1500 kg van.
- A table of the two savings, a bar for each plan, and one sentence say which plan saves more joules.



Net work equals the kinetic energy change.

Comparing energy savings

- Plan A saves 1.69 times 10 to the fifth joules of kinetic energy at each stop.
- Plan B saves 3.35 times 10 to the fifth joules of fuel energy at each acceleration to 25.0 m/s.
- State which route data would decide the better plan.

A car’s kinetic energy change

- A 1000 kg car speeds up from 10.0 m/s to 20.0 m/s over 50.0 m.
- Find delta Ek and the net force along the displacement.
- Name the theorem that links them.

Physics 20

Unit C: Circular motion and energy

Energy transfer technologies

A meteor meets the ground

- A meteor of mass 2.40 times 10 to the fifth kilograms hits at 1.10 times 10 to the fourth m/s.
- Its kinetic energy is 1.45 times 10 to the thirteenth joules, a sudden transfer into the ground.



Efficiency and energy transfer

- A space probe swings past a moving planet and trades speed with that planet.
- Efficiency equals useful output divided by total input.
- A sustainable transfer does the job and looks after the land, the fuel, and the waste.

Key terms

gravity assist

A gravity assist is a close pass by a moving planet that exchanges momentum and energy with a spacecraft.

efficiency

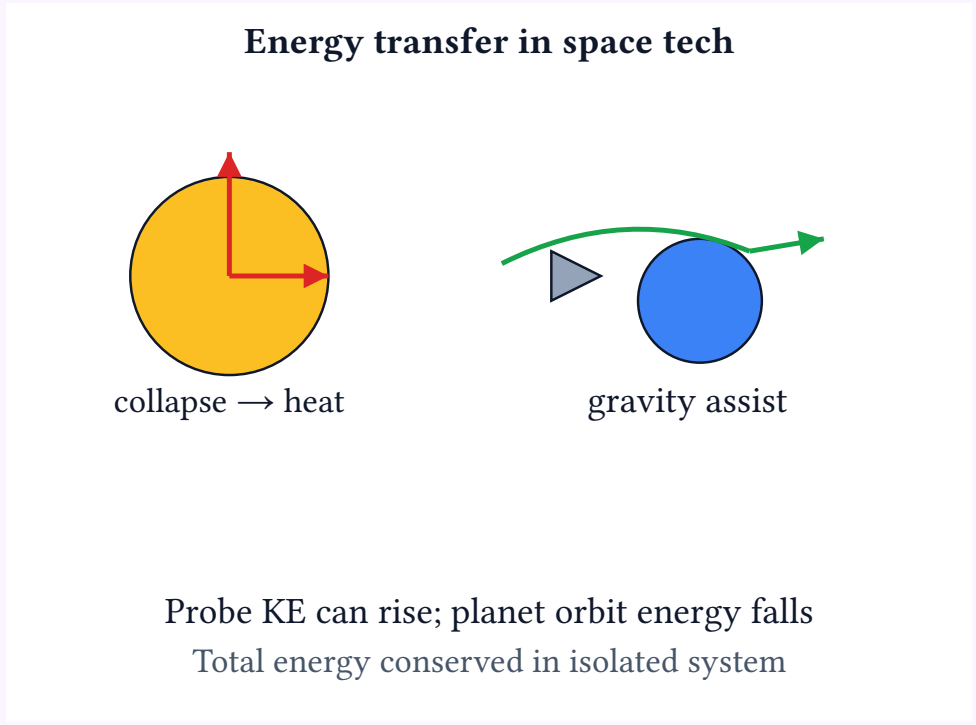
Efficiency is the useful energy output divided by the total energy input. (efficiency = useful output / total input)

sustainable energy transfer

Sustainable energy transfer meets an energy need while caring for the environment that receives the waste and supplies the source.

A collapsing shell and a planetary swing

- A collapsing star turns gravitational potential energy into thermal energy and radiation.
- A space probe swings past a moving planet and trades speed with that planet.
- The probe's kinetic energy can rise while the planet's orbital energy falls by the same amount.

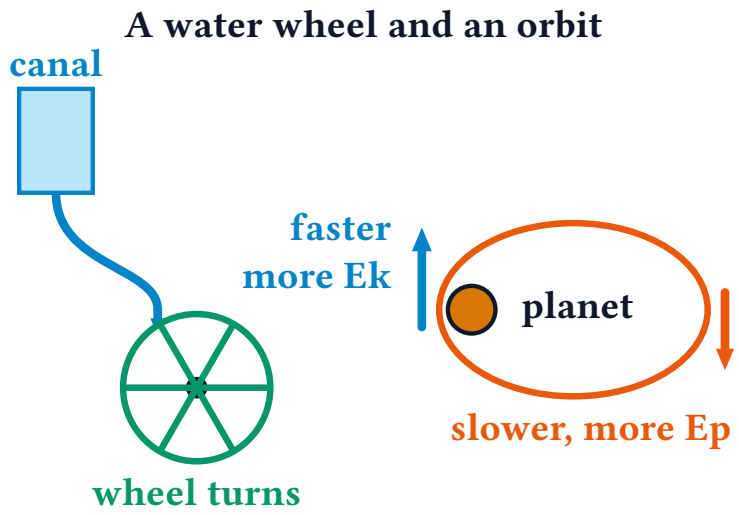


Kinetic energy of the meteor

- Mass 2.40 times 10 to the fifth kilograms, speed 1.10 times 10 to the fourth m/s.
- Ek = one half × $(2.40\times10^{5}\ \text{kg}) \times (1.10\times10^{4}\ \text{m/s})^{2}$.
- That kinetic energy is 1.45×10^{13} J into the ground.

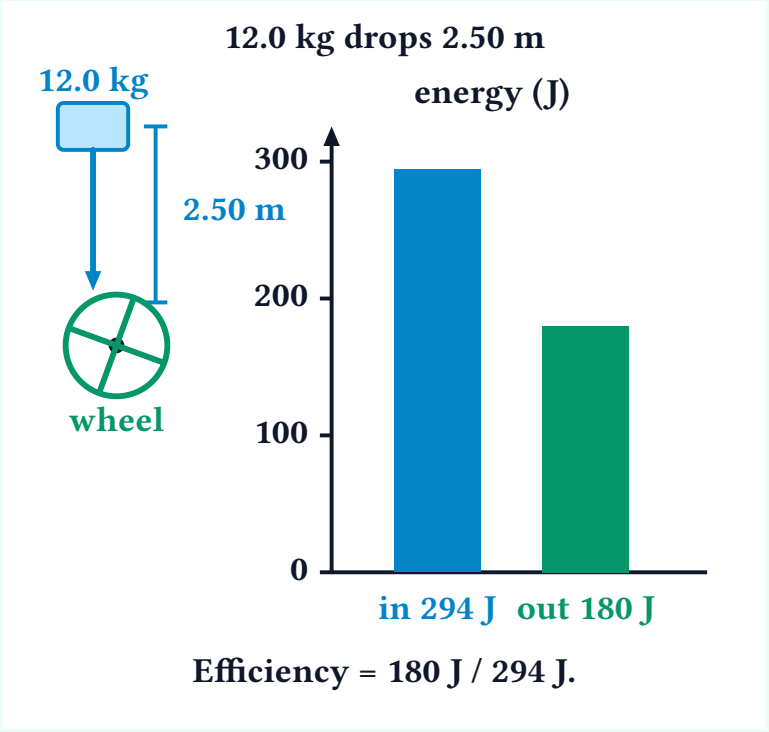
Historical energy technologies

- Closer to the planet the satellite moves faster. Farther out it moves slower, trading kinetic energy and gravitational potential energy.
- Inca terrace canals move water by gravity, and a water wheel turns that motion into rotation.
- Efficiency is useful output over total input, and an Alberta furnace or hydro plant can raise it.



Efficiency of the terrace wheel

- Canal water of mass 12.0 kg drops 2.50 m and can supply 294 J.
- The wheel delivers 180 J of rotation.
- Efficiency is useful output divided by total input.



The furnace ratio

- A home needs 64.0 MJ of useful heat.
- Compare fuel input at efficiency 0.680 with fuel input at efficiency 0.960.
- Say how the higher ratio cares for the surroundings.

Image credits

D. Roddy, U.S. Geological Survey, Barringer Meteor Crater, Arizona, public domain

Physics 20

Unit D: Oscillations and mechanical waves

Simple harmonic motion

A glider returns every 0.628 s

- A 0.250 kg glider on a horizontal air track is pulled 0.060 m to the right of a paint mark and released.
- Each full out and back cycle takes 0.628 s, and the glider keeps reaching that same rightmost point.

Cycle time and the four labels

- Oscillatory motion repeats about equilibrium, and the period T is the time for one cycle.
- Frequency f equals 1 divided by T, so a shorter cycle means a larger frequency in hertz.
- In simple harmonic motion the pull back grows in step with how far you are from the middle. Amplitude is that greatest distance.

Key terms

oscillatory motion

Oscillatory motion is a repeating back and forth motion about an equilibrium position.

simple harmonic motion

Simple harmonic motion is motion due to a restoring force directly proportional to displacement from equilibrium and directed opposite that displacement.

restoring force

A restoring force pulls or pushes an object back toward equilibrium, opposite the displacement. In F = -k x, F is that force, k is the spring stiffness, and x is the displacement from equilibrium. (F = -k x)

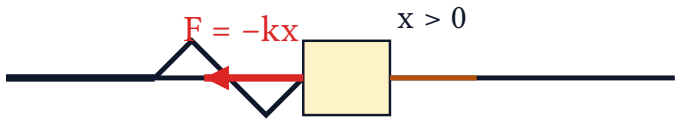
amplitude

Amplitude is the maximum displacement from equilibrium during an oscillation. (A)

The spring force points back

- The force law is F = -k x, with F in newtons, k in newtons per metre, and x the displacement from equilibrium in metres.
- The negative sign means the force points opposite the displacement when the positive direction is away from equilibrium.
- For a horizontal mass spring oscillator, T = 2 pi times the square root of m/k, and m is the mass.

Spring force law



$T = 2\pi\sqrt{(m/k)}$

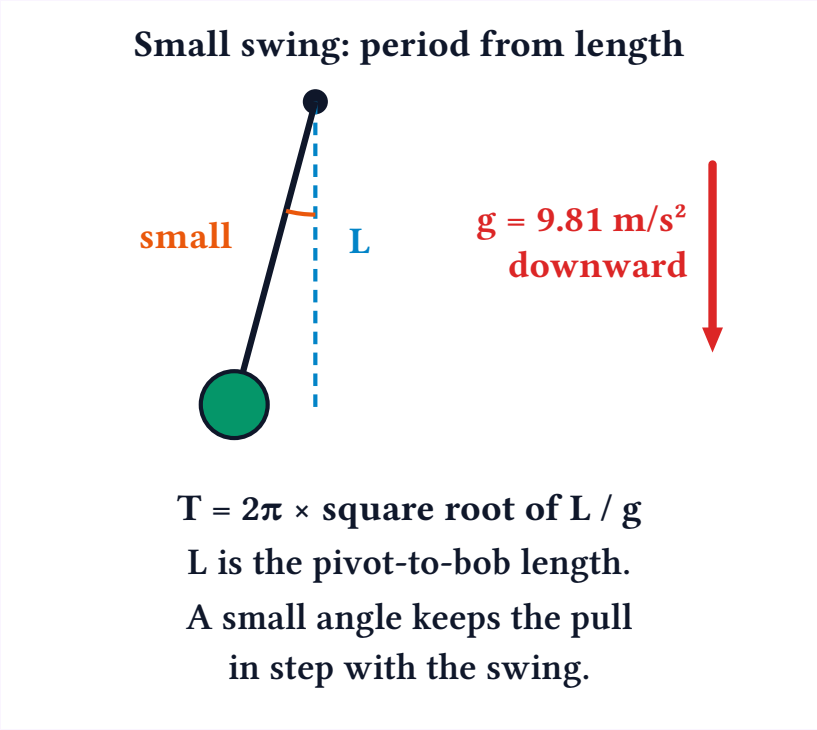
Force points toward equilibrium

Period of a 0.450 kg cart

- A cart of mass 0.450 kg is fixed to a horizontal spring with k = 18.0 N/m.
- T = 2 pi × square root of 0.450 / 18.0 = 0.993 s.
- At +0.080 m, F = -(18.0 N/m)(0.080 m) = −1.44 N.

A small swing and the pendulum clock

- For a simple pendulum at a small angle, T = 2 pi times the square root of L/g.
- The symbol L is the length from the pivot to the centre of the bob, and g is 9.81 m/s squared downward.
- Keep the swing small. Then the pull back grows in step with the distance from the middle.



A stairwell pendulum

- A stairwell pendulum has length 2.20 m and swings through a small angle.
- Find the period with g = 9.81 m/s squared.
- State the speed and the acceleration along the arc at the bottom and at the highest point.

Oscillators

- A 0.200 kg air track glider has k = 50.0 N/m and amplitude 0.040 m.
- Find the period and the restoring force at the positive amplitude.
- State the speed at the amplitude and the acceleration at equilibrium.

Physics 20

Unit D: Oscillations and mechanical waves

Oscillator energy and resonance

Washboard ruts at 10 Hz

- A pickup west of Drumheller rolls at 8.0 m/s over gravel ruts spaced 0.80 m apart.
- The wheels meet a rut ten times each second, and the cab amplitude grows when the suspension springs share that rhythm.

Energy and stiffness

- In an ideal oscillator that keeps its energy to itself, the joules stay the same total while kinetic energy and potential energy trade places.
- The spring constant k is stiffness in newtons per metre. A pendulum period depends on length and on g, which is 9.81 m/s squared downward.
- Resonance is the big swing you get when each push matches the rhythm the object already has.

Key terms

mechanical resonance

Mechanical resonance is a large amplitude that builds when a driving frequency matches the natural frequency of an oscillator.

spring constant

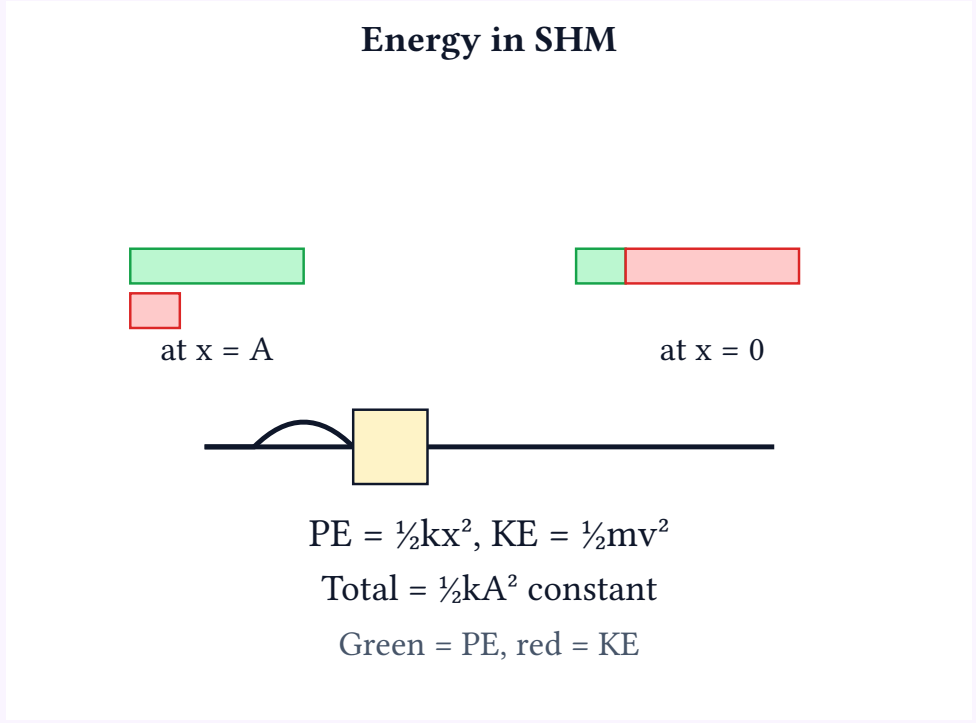
The spring constant is the stiffness of a spring, equal to the magnitude of the force divided by the stretch. (k)

pendulum

A pendulum is a bob on a string or rod that swings through a small angle about a fixed pivot. (T = 2 pi square root of L/g)

Joules trade places and the total holds

- Spring potential energy is one half k x squared, and kinetic energy is one half m v squared.
- At the amplitude the speed is zero and the total energy is one half k A squared.
- At equilibrium the potential energy is zero and the speed is greatest, with the total still equal to one half k A squared.

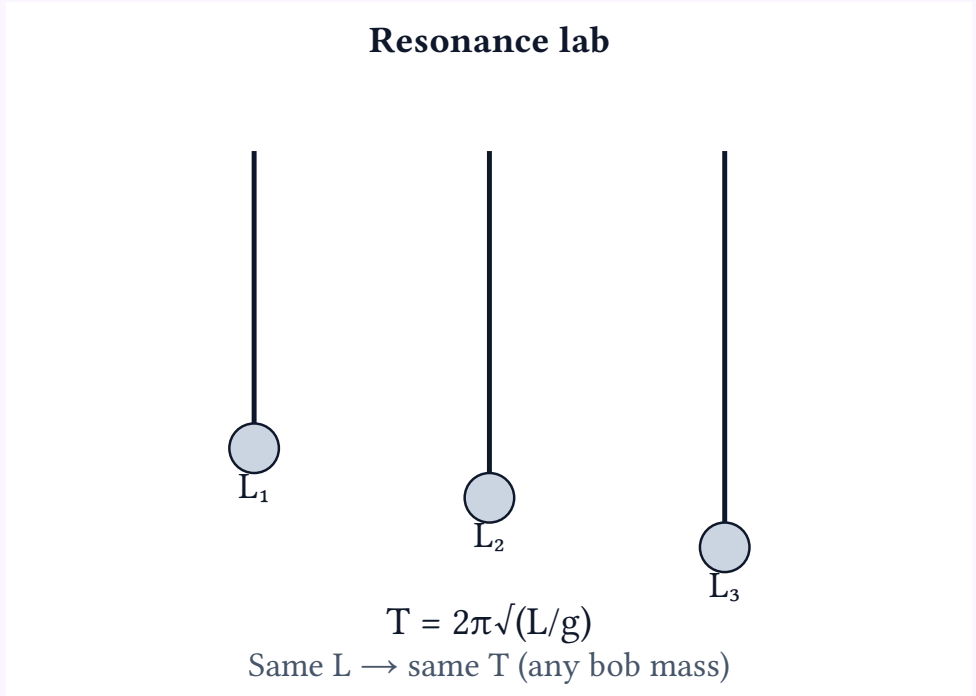


0.144 J in a 45.0 N/m spring

- A 0.180 kg block on a 45.0 N/m spring has amplitude 0.080 m.
- Total energy = one half × 45.0 × $(0.080)^2$ = 0.144 J.
- Greatest speed from one half × 0.180 × v^2 = 0.144 is 1.26 m/s.

Resonance demonstration

- Pendulum data for several lengths should follow T = 2 pi times the square root of L/g.
- Same string length and same g: a heavier bob still has the same period.
- The spring constant comes from F = k x or from the measured period, and a resonance demo stays at a modest amplitude.



Stiffness from a hanging mass

- A 0.400 kg mass stretches a vertical spring by 0.0981 m.
- Find the spring constant from the weight and the stretch.
- A tower sways naturally at 2.40 Hz. A push at 2.40 Hz builds a large sway. A push at 0.70 Hz stays small.

Stored joules and a matched driver

- A 0.180 kg block on a 45.0 N/m spring has amplitude 0.080 m.
- Find the total mechanical energy and the greatest speed.
- The natural frequency is 2.52 Hz. State what a 2.52 Hz driver does to the amplitude.

Physics 20

Unit D: Oscillations and mechanical waves

Properties of mechanical waves

A ribbon stays while the pulse leaves

- A coloured ribbon is taped to one loop of a long coil stretched 6.0 m across the gym floor.
- A sharp push sends a compression 6.0 m in 2.40 s, and the ribbon jitters beside its tape mark.

Names for a travelling disturbance

- A mechanical wave keeps each particle oscillating near its start while energy moves forward.
- If the coil moves sideways while the pulse runs forward, the wave is transverse. If the coil pushes along the pulse, the wave is longitudinal.
- On that travelling shake you measure wavelength, wave speed, period, frequency, amplitude, the wave front, and the ray.

Key terms

mechanical wave

A mechanical wave is a disturbance in which particles of a medium oscillate in simple harmonic motion while energy travels forward.

transverse wave

A transverse wave moves particles of the medium perpendicular to the direction of propagation.

longitudinal wave

A longitudinal wave moves particles of the medium along the direction of propagation.

wavelength

Wavelength is the distance from one crest to the neighbouring crest, measured along the direction of travel. (lambda)

Key terms

wave speed

Wave speed is the speed at which the disturbance travels through the medium. (v)

wave front

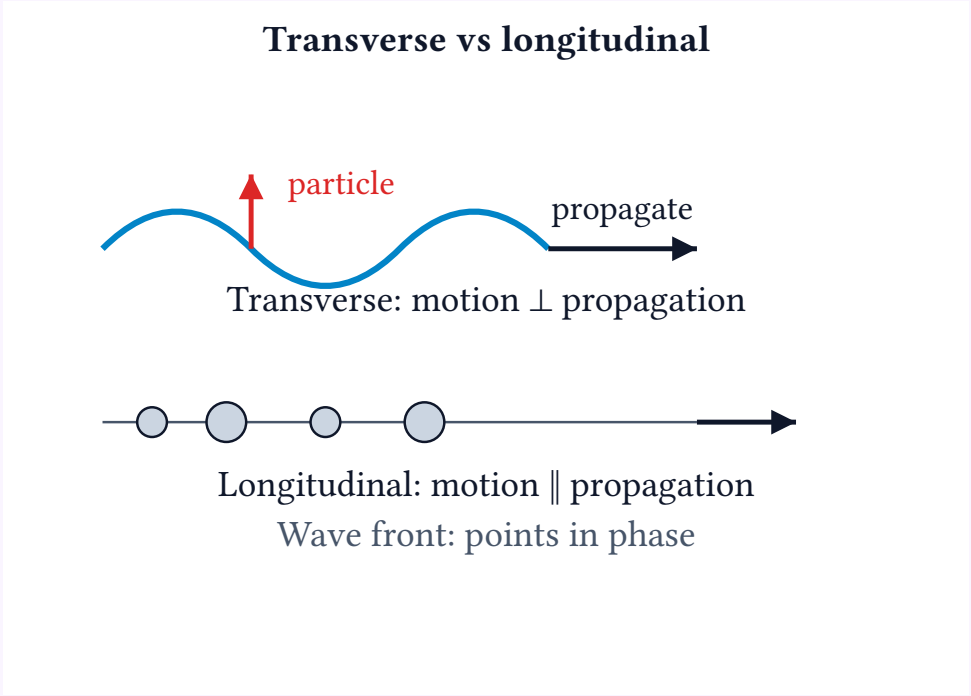
A wave front is a line or surface joining points of the medium that move together at the same stage of the cycle.

ray

A ray is an arrow drawn perpendicular to a wave front, showing the direction of energy travel.

Sideways shakes and lengthwise pushes

- In a transverse wave the particle motion is perpendicular to the direction of propagation.
- In a longitudinal wave the particle motion is along the direction of propagation.
- A wave front is a line through points that are moving together.
- A ray leaves that line at a right angle and shows where the wave is going.



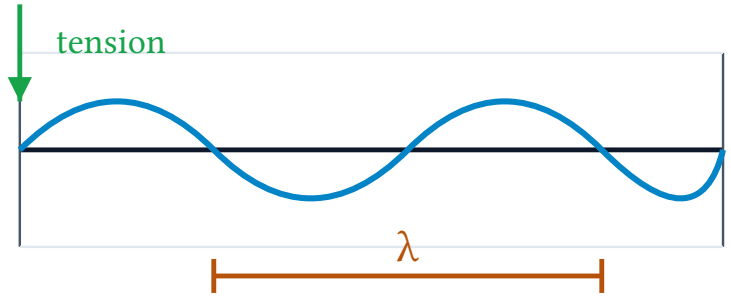
A 686 Hz whistle in warm air

- A whistle of frequency 686 Hz sounds in air at 20 degrees Celsius, where the wave speed is 343 m/s.
- Wavelength = 343 m/s / 686 Hz = 0.500 m.
- Sound in air is a longitudinal wave, so the air particles move along the ray.

The medium sets the wave speed

- Wave speed on a string depends on the tension and the linear density of that string.
- Wave speed of sound in air depends on the temperature of the air.
- With one variable changed and another held constant, v = f lambda predicts the new wavelength.

Wave speed on a medium



$$v = f\lambda$$

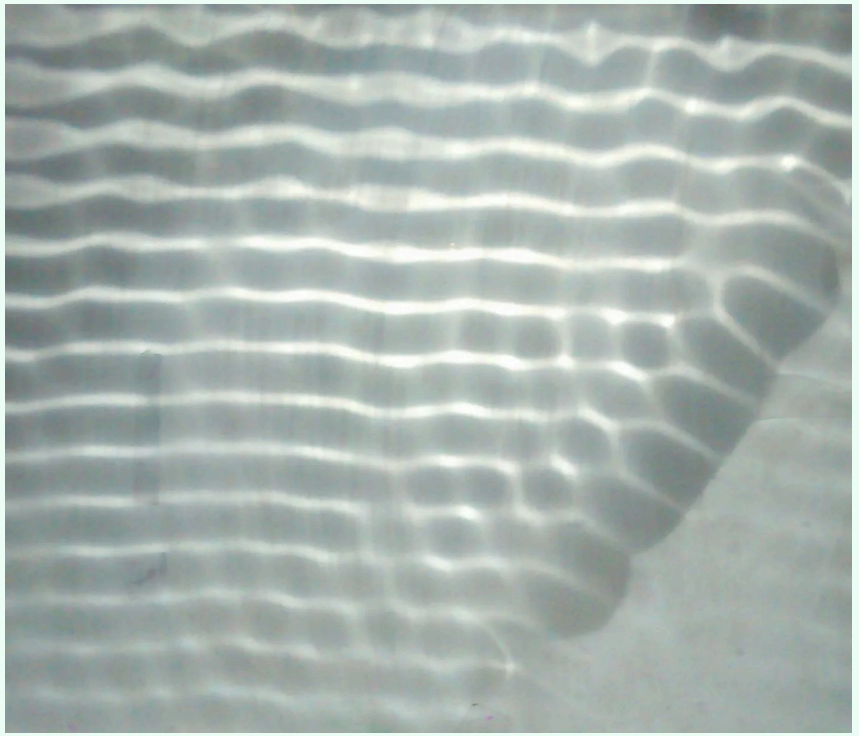
String: v set by tension & density

Sound: v set by air temperature

Hold one variable fixed to predict λ

A ripple tank held at one speed

- A ripple tank shows crests 0.125 m apart, and 4.00 crests pass a dot each second.
- Find the wave speed, then predict the wavelength if the paddle slows to 2.00 Hz in the same water.
- Verify the prediction with v = f lambda.



Harbour crests

- Harbour crests are 2.40 m apart, and a crest passes a piling every 4.00 s.
- Find the wave speed.
- Predict the new wavelength if crests pass every 2.00 s and the harbour water is unchanged.

Image credits

Psgs123xyz (talk) (Uploads)., Reflection of waves observed using a ripple tank., CC0 1.0

Physics 20

Unit D: Oscillations and mechanical waves

Wave interference and the Doppler effect

One clamp flips the pulse

- A 4.0 cm upward pulse runs along a rope toward a clamp screwed to the lab bench.
- The pulse returns upside down, while a second rope with a free ring sends an upright pulse back.

Wave behaviour

- Reflection returns a pulse inverted from a fixed end and upright from a free end.
- Interference is what you see or hear when two waves overlap. A pipe rings loudly when the note matches the air inside.
- You stand still. A moving horn reaches your ear at a different pitch than the pitch the horn makes.

Key terms

reflection

Reflection is the return of a mechanical wave after the pulse meets an end or another boundary.

interference

Interference is the overlap of two waves at one place, giving a resultant amplitude.

acoustic resonance

Acoustic resonance is a large amplitude vibration of an air column when the driving frequency matches a resonant frequency of that column.

Doppler effect

The Doppler effect is the change in heard frequency when a sound source moves toward or away from a stationary observer. (f prime)

Crests that stack and crests that flatten

- Constructive interference happens when crests meet and the amplitudes add.
- Destructive interference happens when a crest meets a trough and the resultant amplitude drops.
- With two sources, count how many wavelengths each path is. That difference tells you whether the waves add or flatten.

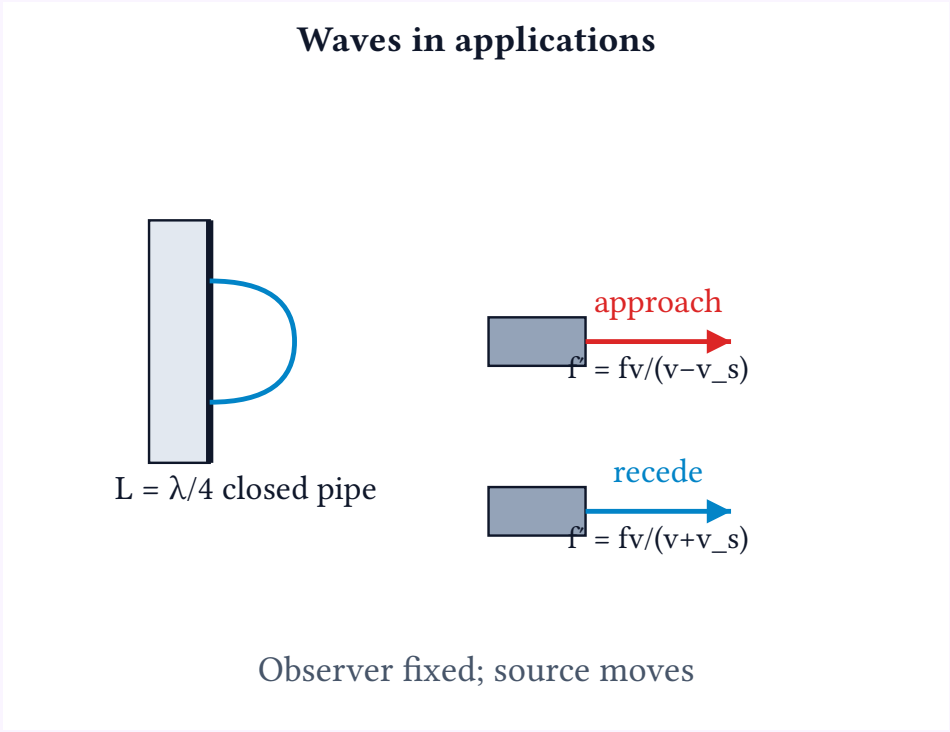


Path differences of 0.80 m and 0.20 m

- Two sources send waves of wavelength 0.40 m.
- Point A differs by 0.80 m, which is 2 wavelengths, so the waves add.
- Point B differs by 0.20 m, half a wavelength, so the waves flatten.

Applications of waves

- A closed pipe first resonates when its length is one quarter of the wavelength.
- You stand still. As the horn approaches, divide f times v by v minus the horn speed.
- As the horn leaves, divide f times v by v plus the horn speed.
- Sonography, sonar, organs, brass, noise tools, and a canoe all use wavelength and wave speed.



Resonance in a 0.180 m pipe

- Find the first resonant frequency of a closed pipe 0.180 m long when v = 343 m/s.
- Check the wave speed with 4 L f.
- Two sources of wavelength 0.40 m meet where the path difference is 0.20 m. Predict the interference.

An ambulance horn

- An ambulance siren has frequency 620 Hz and moves at 22.0 m/s in air where v = 343 m/s.
- Find the frequency heard by a stationary observer as the ambulance approaches.
- Find the frequency heard as the ambulance recedes.

Image credits

Markus Pössel, Interfering surface waves on a lake, CC BY 4.0