AS Physics: Mechanics

written by MJ Bradley

AS Physics: Mechanics Notes

Scalar and Vector Quantities

A scalar quantity has only size. A vector has sized and direction

scalar	vector
distance	displacement
speed	velocity
temperature	force
mass	acceleration
energy	momentum

Whenever you calculate a vector quantity you must give its size and direction

Displacement and Velocity

Displacement is distance in a given direction.

Velocity (ms^{-1}) = displacement (m) / time (s) $v = s/t$

Acceleration

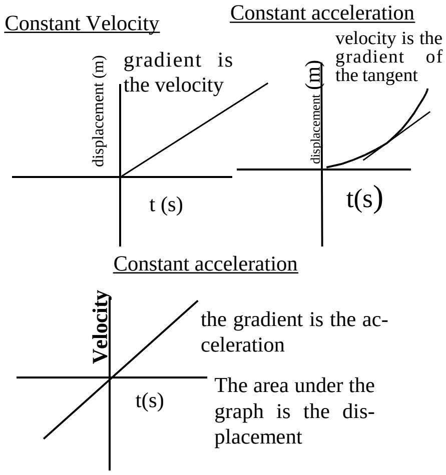
Acceleration is the rate of change of velocity.

An object with constant speed can still be accelerating if its direction is changing because its velocity changes as direction changes.

acceleration (ms^{-2}) = velocity change / time (s), $a = \frac{v-u}{t}$

v = final velocity, u = initial velocity, t = time

Motion Graphs



Equations of Motion for an Object with constant acceleration

$v = u + at$

$v^2 = u^2 + 2as$

$s = ut + 1/2at^2$

1) Write down data
2) Select the appropriate equation

Example: A rocket accelerates at $1000ms^{-2}$ for 20s. What distance is travelled?

$a = 1000ms^{-2}$, $t = 20s$, $s=?$

$s = ut + 1/2at^2 = 1000x20 + 0.5x1000x20^2$

$= 20000 + 200000 = 220000m$

Newtons 1st Law of motion

An object will remain at rest or have constant velocity unless it is acted on by an external force

Newtons 2nd Law of Motion

The acceleration produced by a force when it acts on a body is proportional to the force ***and takes place in the direction of the force***

acceleration (ms^{-2}) = force (N) / mass (kg), $a = f/m$

Defining the Newton

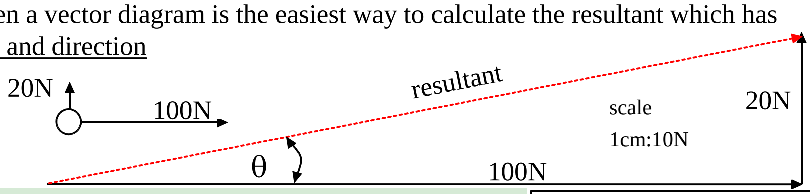
From f = ma we can define 1 N as being the force required to make a 1kg mass accelerate by 1 ms^{-2} $f = 1 \times 1 = 1N$

Mass and Weight

A huge spaceship in deep space is weightless but is still difficult to get moving or stop. Mass is a measure of how difficult it is to change the motion of an object. Weight is the pull of gravity on a mass and very much depends where you are in the universe

Calculations Involving Vectors

Vectors combine together to give a resultant. It could be force, velocity etc. Often a vector diagram is the easiest way to calculate the resultant which has size and direction



Vector addition Rules

1) Using a sensible scale Re-draw the diagram with the tail of one vector starting at the head of the other
2) The line that 'closes' the diagram is the resultant
3) Measure the length of the line and convert back to the quantity using your scale
4) Use a protractor to measure an angle

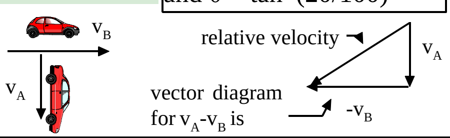
Length of resultant = 10.2cm which is 10.2 x 10 = 102N and θ = 11.3°

The same result would have been obtained using Pythagoras theorm

$a^2 = b^2 + c^2$

and $\theta = \tan^{-1}(20/100)$

Subtracting vectors. For example when calculating the difference in two cars velocities with velocity v_A and v_B the difference is equal to v_A-v_B. The vector v_B must be drawn as $-v_B$

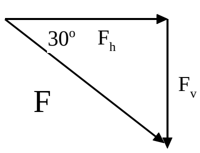


Acceleration due to Gravity(g)

From f = ma, weight w = mg

so g = w/m, and if air resistance is ignored all objects would accelerate to earth at the same rate of $9.8ms^{-2}$. This seems surprising surely heavier obects would accelerate more? They do not because they also have more mass and the two factors cancel each other out

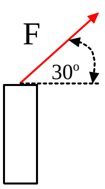
Vectors positive or negative?



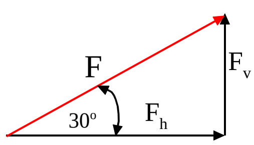
You must be consistent with the signs you give to vectors. If as on a graph you take up and to the right as being positive then $F_h = F\cos30$ and $F_v = -F\sin30$

Vector Components

In two dimensions a vector has a horizontal and vertical component



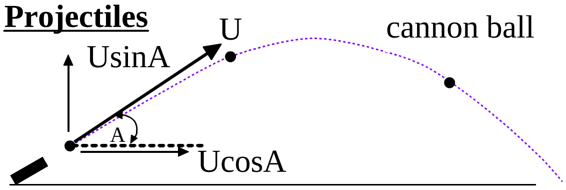
There is a vertical (F_V) and horizontal (F_h) component of the force F pulling this boat. Drawing a sketch of the vectors following our vector rules is helpful



$\sin30 = \frac{F_v}{F}$, $\cos30 = \frac{F_h}{F}$

so $F_v = F\sin30$, and $F_h = F\cos30$

Projectiles



Gravity has no component in the horizontal direction and therefore if we neglect air resistance the projectile will move at constant velocity horizontally. and UcosA = s/t.

In the vertical direction the projectiles acceleration remains at $-10ms^{-2}$ throughout its motion and we must use the equations of motion but remember to apply them in the vertical direction only ie. vertical displacement, vertical velocity. Take care that you are consistent with the signs (+ or -) given to velocity, displacement and g

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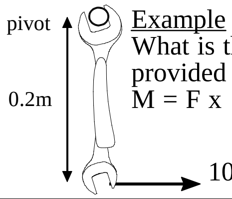
Turning Forces (moments)

A turning force can be called a moment. All moments turn about a point called the pivot. The moment can be made bigger by increasing the force and its distance from the pivot

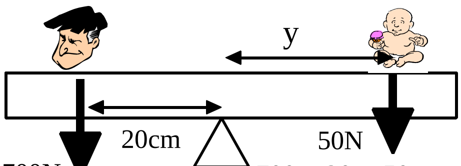
moment = force(N) x perpendicular distance from the pivot to the line of action of the force
(Nm) (m)



Example
What is the moment provided by the spanner?
M = F x D = 10 x 0.2
= 2Nm

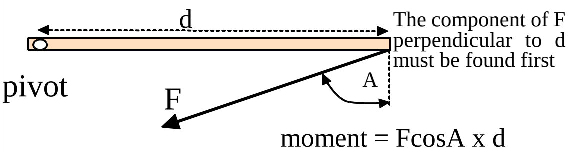
Balance point

At equilibrium the sum of the clockwise moments is equal to the sum of the anticlockwise moments. How far (y) is the baby from the pivot if the seesaw balances?



700 x 20 = 50 x y
y = 240cm

What happens if the distance d and the line of action of the force are not perpendicular?

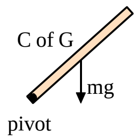


moment = FcosA x d

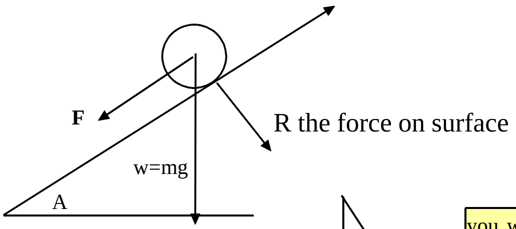
Centre of Gravity

This is the point from which in a body gravity acts. For symmetrical objects with weight evenly distributed it is at the centre. The weight of an object can produce a moment about a pivot. The weight acts from the centre of gravity

A car barrier



The Inclined Plane Vectors can be used to analyse the forces and acceleration of objects. The acceleration of the ball is clearly 0 when the plane is flat but increases as it becomes more vertical and eventually g when it is completely vertical. The force causing the ball to accelerate is the component of the balls weight down the slope

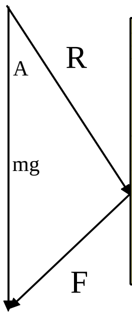


Drawing a vector diagram gives

F = mgsinA, the force down the slope

from f = ma, mgsinA = ma

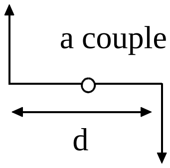
so a = gsinA, when A =90°
a = g



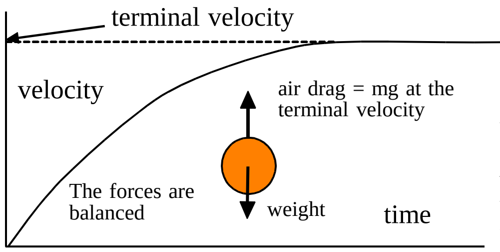
you will need to use your knowledge of angles to satisfy yourself that the angle marked is A the same as the angle of the slope

A Couple Two forces acting on an object equal in size and opposite in direction separated by a perpendicular distance d

torque of a couple = force x perpendicular distance between the forces
(Nm)



Equilibrium: A system is in equilibrium if
1) the resultant force on it is zero
2) the sum of the clockwise and anticlockwise moments is zero



Terminal Velocity

Initially the forces on the ball are unbalanced and it accelerates. When the drag balances the weight the terminal velocity is reached

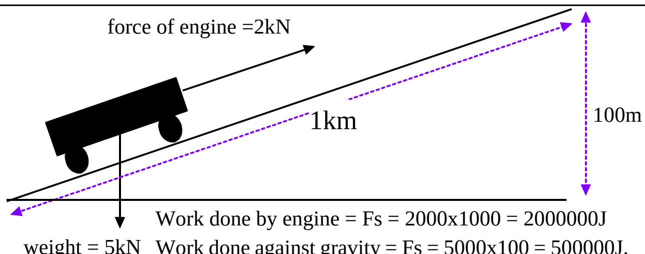
Work

Work is done when a force moves an object through a distance. Work is a transfer of energy. E.g. lifting a book chemical potential energy in muscles is changed to gravitational potential energy

Work Done = force x distance in direction of force
(J) (N) (m)

W =Fx s

The Joule. If a 1N weight is lifted through 1m then the work, W = Fxs = 1x1 =1J and this is the definition of 1 joule



Work done by engine = Fs = 2000x1000 = 2000000J
Work done against gravity = Fs = 5000x100 = 500000J. The work done by the engine is greater because it is also having to work against friction

Power

Power is how quickly work is done. If a machine does a lot of work in a short space of time it has a high power. It is measured in joules per second which scientists call watts (W)

Power = work done (J) / time (s)
(W)

Example: The power of a machine that does 2000J of work in 2s is
P = WD / t = 2000 / 2 = 500W

Kinetic Energy

Anything which moves has kinetic energy. If an object has a big mass and a high speed it has a very big kinetic energy

kinetic energy = 1/2 x mass x velocity²
(J) (kg) (m/s)

Examples:What is the Kinetic energy of a 100 000kg train moving with a velocity of 30m/s?
answer: KE = 1/2 x m x v^2
= 1/2 x 100 000 x 30^2
= 1/2 x 100 000 x 900 = 45000000J

Gravitational Potential Energy

This is the energy something has due to it height above the ground

Potential energy = mass x g x height
(J) (kg) (m)
g = 10 m/s²

It is often more meaningful to describe the change in PE, ΔPE

ΔPE = mgΔh

Example What is the potential energy gain of a steel girder of mass 1000kg when a crane lifts it to a height of 100m.?
ΔPE = m x g x Δh = 1000 x 10 x 100
= 1000000J

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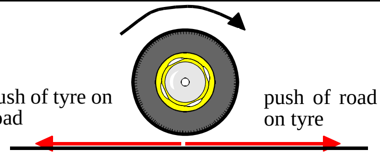
Newtons III Law

When two bodies interact they exert equal and opposite forces on each other

When walking your foot pushes back on the road and the road pushes with an equal and opposite forwards force which causes you to accelerate forwards. The Earth beneath you also accelerates backwards but you do not notice it because the Earth is so massive

Motive Force

This is provided by an engine and delivered by a torque to the wheels. The wheels push back on the road and the road pushes forward with an equal opposite force (friction)



In icy weather there is not much friction available to provide the forward force. if the push of the tyre on the road exceeds this limit the wheel skids

Braking

Brakes work using friction to apply a torque to the wheels in the opposite direction to the torque provided by the engine

Motive Power

Motive power = force x speed
(W) (N) (ms^{-1})
P = Fv

Car safety Features

Crumple zones: These absorb kinetic energy. As they crumple the car decelerates less rapidly and the forces on the occupant are reduced.

Air bags: As the person hits the bag they decelerate less rapidly than if they were to hit the steering wheel directly and the forces on them are reduced.

Seat belts: These keep an occupant in their seat. They need to be slightly stretchy otherwise the forces on the person will be to large. There is a danger that seat belts will have gone past their elastic limit after a collision.

Forces in Collisions

The deceleration in a collision is huge because the time over which the collisions occur is tiny. If the deceleration is big then the forces involved must be very big because F =ma. If the time of the collisions can be increased then the deceleration and the forces involved are also reduced.

Stopping Distance

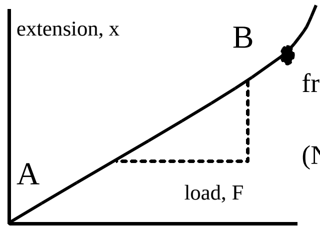
stopping distance = thinking distance + braking distance

Thinking distance is the distance you go while reacting. It is affected by alcohol, drugs and speed
Braking distance is the distance travelled once the foot is on the brake and is affected by how hard the brakes are pressed (the harder the pedal is pressed the more the friction between the brake pad and wheel), speed, weather, road and tyre conditions. Anything which reduces friction will increase braking distance.

Deforming Solids: Hookes Law

An object obeys Hooke's law if the extension is proportional to the load

F =kx, k is the spring constant, k=F/x and is the force per unit extension



from this graph
k = 1 / gradient
(N/m)

Between A and B the extension is proportional to the load. At B however the elastic limit has been reached and the material no longer returns to its original shape

Stress and Strain

How a material will extend under load very much depends on its dimensions ie. its original length and cross-sectional area. To be able to compare the stiffness of materials it is more useful to consider the load per m^2 (stress) and the fractional increase in length (strain)

stress = force (N) / area (m^2)
(Nm^{-2})

strain = extension / original length
(no unit)

Youngs Modulus - a measure of stiffness

If the strain in a material is very small when a high stress is being applied then the material is very stiff

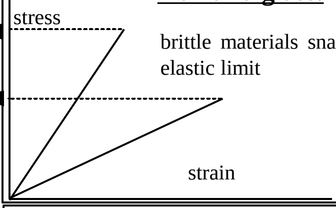
Young's modulus = stress (Nm^{-2}) / strain
(Nm^{-2})

Young's modulus is a constant unique to a particular material and is independent of dimensions and allows the stiffness of materials to be compared directly

Ultimate tensile stress

The maximum stress at the breaking point of the material

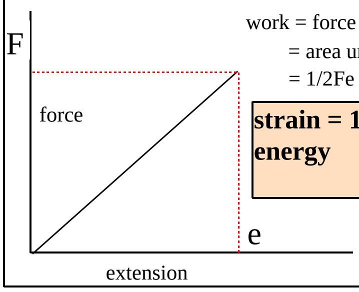
Brittle materials e.g. cast iron and glass.



brittle materials snap at their elastic limit

Strain Energy

When an elastic material is stretched work is done and the energy is transferred as strain energy in the material



work = force x extension
= area under the graph
= 1/2Fe

strain energy = 1/2Fe

Elastic and Plastic deformation

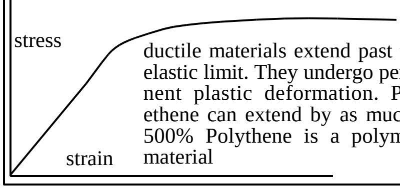
Elastic - material returns to its original shape when the load is removed

Plastic - does not return to its original shape when the load is removed

Density: this is a measure of how compact a substance is

density = mass (kg) / volume (m^3)
(kgm^{-3})

Ductile Materials e.g. copper



ductile materials extend past their elastic limit. They undergo permanent plastic deformation. Polyethene can extend by as much as 500% Polythene is a polymeric material

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Pressure: this is a measure of how concentrated force is - like stress

pressure = force (N) / area (m^2)
(Nm^{-2})
(Pa)