Force and Motion

Name _____ Date _____

By the end of this topic I can…

- state and apply Newton's three laws of motion
- draw free-body diagrams and find the resultant force on a body
- describe weight, drag, upthrust, normal contact and friction, and explain terminal velocity
- solve problems on slopes and for connected bodies

Newton's laws of motion

A force appears when two bodies interact. The **resultant** (net) force is the _____ of all the forces on an object. Forces you will meet: _____, tension, normal contact, friction, drag, upthrust, electric and magnetic forces.

- a resultant force can change the _____, the _____ or the _____ of an object, or make it rotate
- a **point mass** is an idealisation: the object has mass but takes up no space

Newton's first law

An object stays at _____ or continues to move at _____ unless acted on by a _____.

- the tendency of a body to resist changes in its motion is its **inertia**
- with no resultant force the object is in **equilibrium**

Newton's second law

The _____ of an object is directly proportional to the _____ on it and inversely proportional to its _____; it is in the _____ as the resultant force:

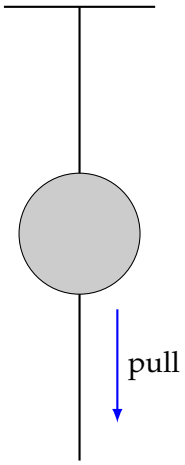
- the **newton** (N) is the force that gives a mass of _____ an acceleration of _____, so $1\ \text{N} = 1\ \text{kg m s}^{-2}$

• **mass** is the property of a body that resists _____ (a measure of its inertia)

Example 3.1 A box of 6.0 kg is being pushed along a horizontal surface with a force of 30 N. The resistive force acting is 21 N. What is the acceleration of the box?

Example 3.2 A car of mass 800 kg is travelling at a speed of 20 m s^{-1}. The driver then operates the brake pedal so a braking force of 2000 N gradually brings the car to stop. (a) What is the deceleration for the car? (b) What is the stopping distance?

Example 3.3 A massive ball is suspended on a string. A second string is attached to the bottom of the ball. If one pulls the bottom string with a gradually increasing force, does the top string or the bottom string break first? What if the bottom string is jerked, which string breaks?



Newton's third law

When body A exerts a force on body B, body B exerts a force on A that is _____, _____ and of the _____. The two forces act on _____ bodies.

Example 3.4 Suggest the action and reaction force in the following cases: (a) A person stands on a bathroom scale. (b) A helicopter hovers in air. (c) The earth orbits around the sun.

Free-body diagrams

A **free-body diagram** shows one object with arrows for every force acting *on it*. Routine:

• (1) draw the FBD; (2) _____ forces and find the resultant; (3) apply _____; (4) solve for the acceleration; (5) use the _____ to find speeds, distances and times

Types of forces

Weight

The **weight** of an object is the _____ on it from the Earth:



$g \approx$ _____ N kg^{-1} is the _____.

• weight is a _____ measured in newtons; mass is a _____ measured in kilograms

• mass is the same everywhere; weight changes with the _____

Example 3.5 An astronaut finds that he weighs 300 N on the surface of Mars, where the gravitational field strength is known to be 3.7 N kg^{-1}. Find his mass and hence estimate his weight if he returns to his home on the Earth.

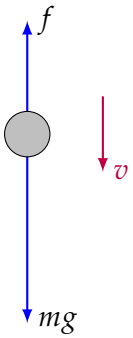
Free fall

With gravity as the only force, $F_{net} = W$, so $ma = mg$:

Free-fall acceleration equals the field strength and is _____.

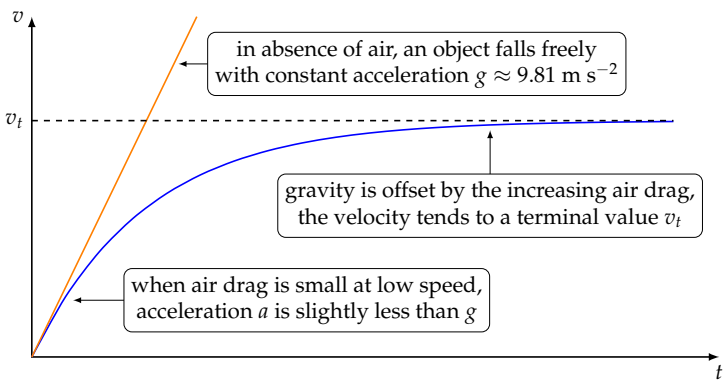
Drag and terminal velocity

Drag is the force on an object moving through a fluid. It acts _____ to the motion, and increases with the _____, the cross-sectional _____ and the _____ of the fluid (and depends on shape).

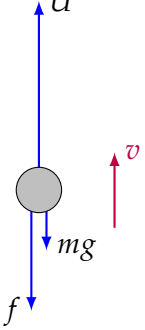


Falling through air: $F_{net} = mg - f = ma$.

- at the start $v = 0$, $f = 0$ so $a =$ _____
- as v increases, f increases, F_{net} _____ and the acceleration decreases
- when $f = mg$ the resultant force is _____, $a = 0$, and the object falls at constant **terminal velocity**



Velocity–time graph of an object falling through air.

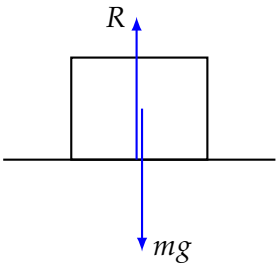


A bubble rising in a liquid has weight mg down, drag f down and _____ U up: $F_{\text{net}} = U - mg - f$. At terminal speed $U =$ _____.

Example 3.6 An object of 5.0 kg falls through the atmosphere from a very high altitude. After some time, it falls at a constant speed of 70 m s^{-1}. Assume there is no significant change in gravitational field during the fall and the air resistance is proportional to speed: $f = bv$. (a) Find the value of the coefficient k. (b) Find the acceleration of the object when it is falling at 30 m s^{-1}.

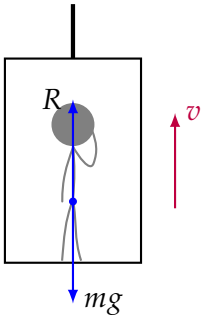
Normal contact force

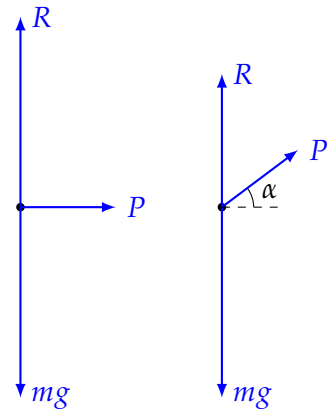
The **normal contact force** R is the component of the contact force _____ to the surfaces. It comes from the _____ between atoms.



Example 3.7 A box of mass $m = 4.0$ kg is resting on a horizontal ground. What is the normal contact force acting?

Example 3.8 A man of 80 kg stands in a lift. Find his apparent weight, i.e., the contact force, when the lift is (a) moving upwards at steady speed of 2.0 m s^{-1}, (b) accelerating upwards at 2.0 m s^{-2}, (c) moving upwards but slowing down at a deceleration of 1.5 m s^{-2}.





(a) (b)

Example 3.9 A sleigh of mass 15 kg lies at rest on an icy ground. The surface is frictionless. A force P of 75 N is applied to the sleigh. Find the normal contact force and the acceleration of the sleigh if P is acting (a) horizontally, (b) at an angle α to the horizontal where $\tan\alpha = \frac{3}{4}$.

Friction

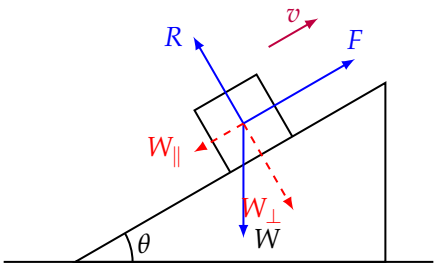
Friction is the component of the contact force _____ to the surfaces; it opposes (relative) sliding.

- **static friction**: acts when surfaces _____ to slide; it adjusts to equal the applied force, up to a _____
- **kinetic (dynamic) friction**: acts when surfaces are _____

Slopes and connected bodies

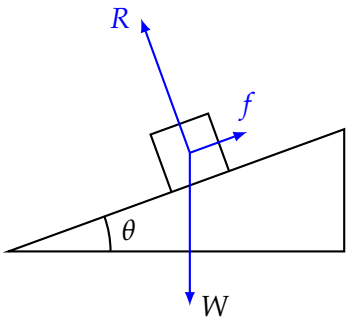
Inclined slopes

Resolve all forces _____ and _____ to the slope:

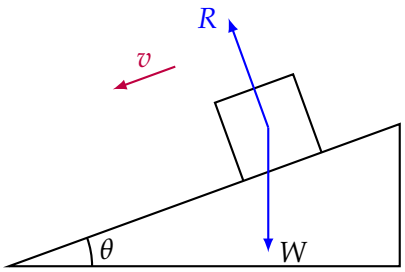


Resolving the weight on a slope.

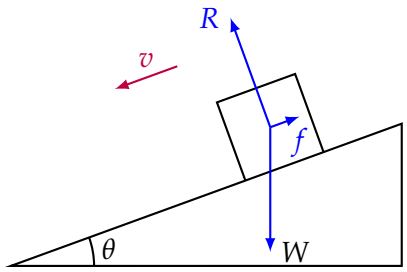
Example 3.10 A block of mass m stays at rest on an inclined plane. The plane makes an angle θ with the horizontal. Find the normal contact force R and the frictional force f acting on the block.



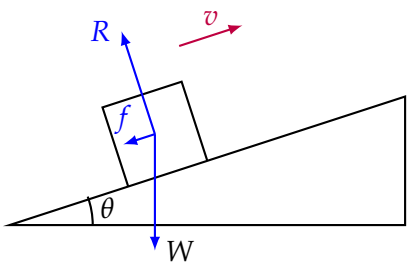
Example 3.11 A block of mass m slides down a *smooth* slope. The angle of the slope to the horizontal is θ. Find the acceleration of the block.



Example 3.12 A block of mass 2.0 kg slides down a rough slope from rest. The slope is inclined at angle $\theta = 20^\circ$ to the horizontal, and the block experiences a constant friction of 5.0 N. (a) What is the block's acceleration? (b) What is the distance travelled in 2.5 seconds?

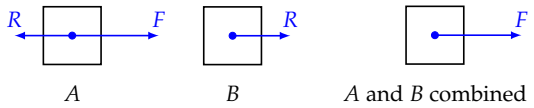


Example 3.13 A block of mass 3.0 kg is travelling up an inclined slope at an initial speed of 2.8 m s^{-1}. The slope makes an angle of 18° with the horizontal. A constant friction of 7.5 N acts on the block.
(a) What is the block's deceleration?
(b) How far does the block travel along the slope before its speed decreases to zero?
(c) Suggest whether the block could stay on the slope.



Connected bodies

Treat each body separately (internal forces such as tension come in equal and opposite pairs), or the whole system together (only _____ forces matter). Two of the three equations are independent.

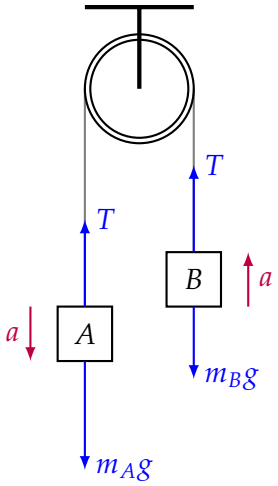


A *B* *A* and *B* combined

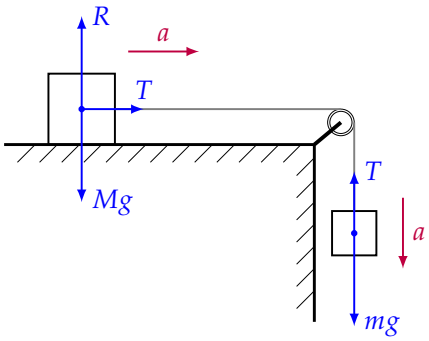
Example 3.14 Two boxes A and B are placed on a smooth surface. They are accelerated together by a horizontal force F as shown. Find the acceleration and the contact force between them.

Example 3.15 A vehicle of mass 1500 kg is towing a trailer of mass 500 kg by a light inextensible tow-bar. The engine of the vehicle exerts a driving force of 9600 N, and the tractor and the trailer experience resistances of 3600 N and 1800 N respectively. Find the acceleration of the vehicle and the tension in the tow-bar.

Example 3.16 Two blocks of mass m_A and m_B ($m_A > m_B$) are joined together by a light inextensible string. The string passes over a smooth pulley as shown. The two blocks are suddenly released from rest. Find the acceleration of each block and the tension in the string.



Example 3.17 A mass $M = 4.0$ kg is attached to a block of mass $m = 2.0$ kg through a light string which passes over a frictionless pulley as shown. When both masses are released, find the acceleration and the tension in the string.



Practice questions

Question 3.1 A little girl tries to lift a luggage bag of mass 25 kg. She pulls upwards with a force of 150 N. The bag does not move. What is the normal reaction from the floor?

Question 3.2 A worker is pulling a wagon of mass of 40 kg across a lawn at a constant velocity. He applies a force of 200 N at an angle of 15° above the horizontal. (a) Draw a free-body diagram for the wagon. (b) Find the frictional force. (c) Find the normal contact force.

Question 3.3 (a) Forces of 3.0 N and 4.0 N act at right angles upon a mass of 160 g. What is the acceleration produced? (b) If the angle between the two forces are allowed to vary, what is the maximum possible acceleration they produce on the same mass? (c) What about the minimum possible acceleration?

Question 3.4 A rocket of mass 30,000 kg is launched vertically upwards at uniform acceleration of 1.6 m s^{-2}. What is the minimum thrust force required?

Question 3.5 A fire-fighter of mass 85 kg slides down a vertical pole. He descends through a distance of 6.0 m in 2.0 seconds. (a) Find the average acceleration. (b) Find the average frictional force acting on the fire-fighter.

Question 3.6 A girl stands onto a bathroom scale and finds the reading is 35.0 kg. She then takes the scale into a lift, what mass reading would she observe if the lift (a) is going down at a constant speed, (b) is accelerating downwards at 2.1 m s^{-2}?

Question 3.7 A small mass slides down a frictionless slope with an acceleration of 2.8 m s^{-2}. Determine the angle that the slope makes with the horizontal.

Question 3.8 A car of mass 1400 kg is moving up a slope at a constant velocity of 13.5 m s^{-1}. The slope makes an angle of 6.0° to the horizontal. Total resistive force of 650 N acts on the car. What is the driving force required to push the car up the slope?

Question 3.9 A shopping trolley somehow loses control and runs down a straight slope from rest. The slope makes an angle of 3.0° to the horizontal. The resistive force acting on the trolley is a constant 15 N. The trolley and its contents have a total mass of 40 kg. (a) Find the acceleration of the trolley. (b) Determine the time for the trolley to travel a distance of 4.0 m along the the slope. (c) Suggest why the slope in shopping malls are not made any steeper.

Question 3.10 Block A of mass 5.0 kg is connected by means of a light string to block B of mass 3.0 kg. The two blocks are placed on a horizontal table. A force of 30 N is applied to pull on block A. Given that the friction on each block is 30% of its own weight. (a) Find the acceleration of the blocks. (b) Find the tension in the string.