**Chapter 9: Force, mass and momentum**

***Please remember to photocopy 4 pages onto one sheet by going A3→A4 and using back to back on the photocopier***

*Odd as it may seem, most people’s views about motion are part of a system of physics that was proposed more than 2,000 years ago and was experimentally shown to be inadequate at least 1,400 years ago.*

I. Bernard Cohen

**Questions to make you think**

The following questions are liable to appear on your end-of-chapter test:

1. If only one force acts on an object, what happens the object (your answer needs to be as specific as possible)?



1. There is a gravitational force of attraction between you and the planet you are standing on.  
   Which exerts the force greater gravitational force – the planet on you or you on the planet (or is there a third option)?

Refer to one of Newton’s laws in your answer.

1. You’re holding onto a helium balloon in a car when it brakes suddenly. What happens to you? Why?  
   What happens to the helium balloon? Why?  
   Check your answer by looking it up on YouTube.
2. There is book resting on a table. There is a gravitational force pulling the book down. Yet the book is not accelerating downwards; therefore there must be an equal force opposing this gravitational force. What is this force?  
   You can’t say ‘the table’; a table is not a force – a table is a table.
3. An apple is attracted to the Earth with a force of approximately one newton.   
   Is the Earth attracted to the apple?   
   If so what is the size of this force? Is it likely to be less than, equal to or greater than the size of the force that the apple experiences?  
   It the Earth does experience a force, then why doesn’t it move (or accelerate) towards the apple?
4. Show how each of Newton’s three laws of motion play a part in explaining how a player can develop concussion when tackled.
5. A truck of mass 10000 kg, travelling at 100 m s-1 crashes into a car of mass 1000 kg which is at rest.

Which experiences the greater force throughout the collision?

1. It’s easier to lift a stone on the moon than on Earth but you’re as likely to break your toe by kicking it on the moon as on Earth. Why?
2. Anybody remember the story of the apple that fell on Newton’s head?  
   What was so significant about that story?

FYI: An apple weighs approximately 1 newton.

**Definition of *a force***A *force* is anything which has the potential to cause an object to accelerate.

The unit of force is the *newton* (N)\*.

**Definition of *the Newton***

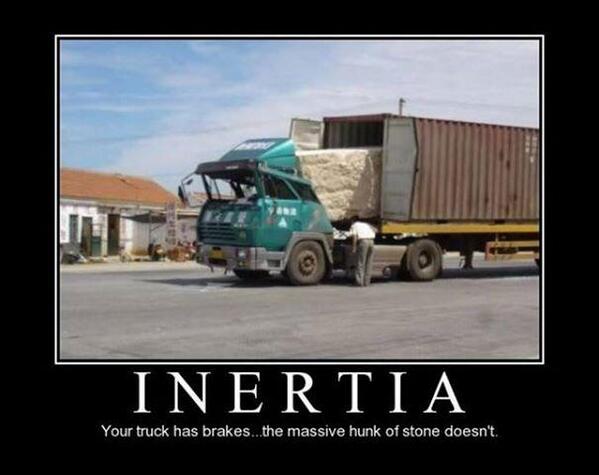
A force of 1 N gives a mass of 1 kg an acceleration of 1 m s-2.

**What is *mass*?\***

The mass of an object is a measure of its *inertia.*

The inertia of an object in turn is a measure of the resistance which the object has to a change in its state of motion.

The unit of mass is the ***kilogram* (kg).**

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**Relationship between Force, Mass and Acceleration**

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**Force = mass** × **acceleration**

**F = ma**

Always remember: “**AN UNBALANCED FORCE PRODUCES AN ACCELERATION**”

**Momentum**

**Momentum = mass × velocity**

**ρ = mv**

Thesymbol of momentum is ρ;pronounced “row”**)**

The unit of momentum is the *kilogram metre per second* (kg m s-1) OR *newton second* (N s)

Momentum is a makey-uppy term. The only reason we bother with it is because this quantity (the product of mass and velocity) turns out to be very important when analysing collisions. It turns out that whoever created the universe had a particular fondness for this quantity, and made it one of the chief ingredients in one of the most fundamental principles in all of physics: *the* *principle of conservation of momentum*.

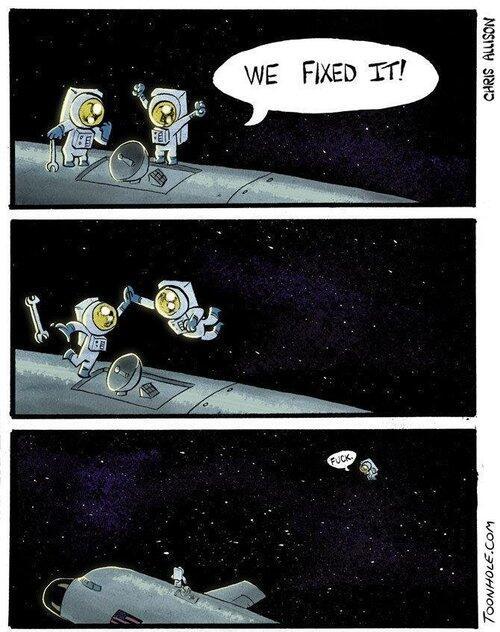
**The principle of conservation of momentum**

**In any interaction, the total momentum beforehand is equal to the total momentum afterwards *provided no external forces act on the system*.**

(If you forget the bit in italics you lose half marks!)

**Areas where the principle of conservation of momentum applies**

* Collisions of every description (including ball games)
* Jet aircraft
* Sneezing

**Points to note**

* It one object collides with another then we can represent it mathematically as follows:

**m1u1 + m2u2 = m1v1 + m2v2**

Note that *initial* and *final* velocity in this context refers to velocity *just* *before* and *immediately after* impact.

* If one object collides with another and the two objects coalesce (stick together) then there is only one (common velocity) after collision, so the above equation becomes:

**m1 u1 + m2 u2 = (m1 + m2)v3**

* **Momentum is a vector quantity.** This means that the following (seemingly crazy) idea is allowed. You can have a situation where there’s no momentum to begin with, like a bullet sitting in a rifle. Now if we fire the gun, the bullet goes forward and the gun recoils in the opposite direction. In this case they both gained the same amount of momentum (where there was none before), but mathematically we describe one momentum as positive and the other as negative (because opposite directions) therefore the total is still zero.

Strange but true.

And this applies in many contexts (jet aircraft above, air escaping from a balloon, two skaters pushing against each other, man jumping off a boat, or astronauts doing high-fives. The first equation can then be reduced to:

**0 = (m1 v1) + (m2 v2)**

where one of the velocities will turn out to be negative.

**Friction**

Friction is a force which opposes the ***relative*** motion between two objects.

Examples of friction: brakes, walking, air resistance

**Newton’s Laws of Motion**

1. **Newton’s first law of motion** states that every object will continue to travel at constant velocity unless an (unbalanced) external force acts on it.
2. **Newton’s second law of motion** states that *the rate of* change of an object’s momentum is directly proportional to the force which caused it, and takes place in the direction of the force.

*{if you apply twice as much force (within the same time) then the momentum changes twice as fast.}*

*{If you think about it, this second law actually makes the first law redundant. Can you see why?}*

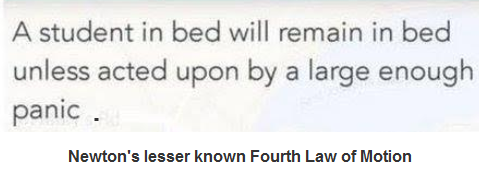
1. **Newton’s third law of motion**\* states that when objects interact they exert equal but opposite forces on each other.

**Exam tip:**

For Newton’s second law don’t forget the phrase ‘*rate of’* change – it’s easy to leave it out and end up with half marks.

Newton originally wrote these in his famous book *Principia*. The convention at the time was to write learned books in Latin. Because these are three of the most important laws in all of Science it is expected that you will learn both the English and the Latin versions. It’s not as difficult as it might first seem.   
Begin by trying to translate from Latin to English

1. Corpus omne perseverare in statu suo quiscendi vel movendi uniformiter in directum, nisi quatenus a viribus impressis cogitur statum illum mutare.
2. Mutationem motus proportionalem esse vi motrici impressae, & fieri secundum lineam rectam qua vis illa imprimitur.
3. Actioni contrariam semper & aequalem esse reactionem: sive corporum duorum actiones in se mutuo semper esse aequales & in partes contrarias dirigi.

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**To Show that F = ma is a special case of Newton’s Second Law**

From Newton II: Force is proportional to the rate of change of momentum

F = k (ma) F = ma

Note: k = 1 because of how we define the newton: (a force of 1 N gives a mass of 1 kg an acceleration of 1 m s-2)\*

**Impulse**

**Change in momentum is also known as ‘impulse’**

**Impulse = mv – mu**

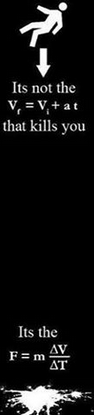
Let’s look again at the derivation above:

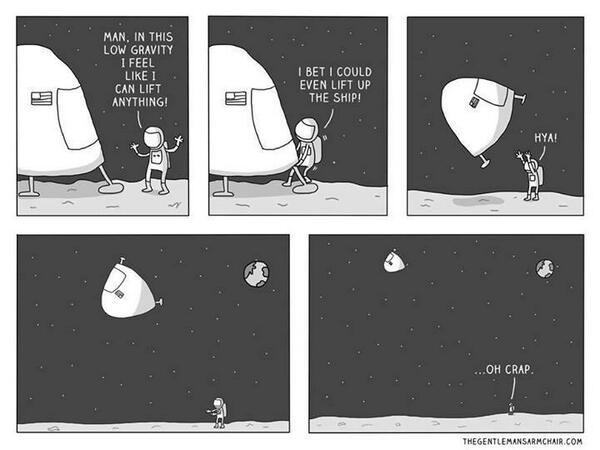
but k = 1 as above **Ft = (mv – mu)\***

This relationship is important when trying to improve performance in ball games; when you want to change the momentum of a ball you need to either increase the force applied (not always easy to do) or else increase the time for which the force is applied (this can come with practice.

This formula was required to answer a question in 2008 and 2014.

**Why use the term *impulse*?**  
Because the force associated with this change in momentum (due to a collision of some sort) is exerted over a very short period of time, and Newton wanted to distinguish this from a longer-acting force which causes an object to accelerate over a long period of time, for which he was more likely to use *F = ma*



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**The relationship between mass and weight**

**The weight of an object is a measure of the force of the Earth’s gravitational force acting on it.**

Because weight is a force, it follows that the unit of weight is also the newton.

Mathematically weight = mass × gravitational field strength

(where *gravitational field strength* is a measure of the strength of the Earth’s gravitational field at that point).

**W = mg**

The units of gravitational field strength are N/kg (can you see why?).

Now it just so happens (nobody is quite sure why) that the value of *gravitational field strength* is the same as the value for *acceleration due to gravity* (9.8 m s-2 on the surface of the Earth). So you will often see the relationship above written in textbooks where *g* is said to represent acceleration due to gravity (with units of m s-2). The number may be the same, but *g* most definitely does not represent acceleration due to gravity in this context.

The textbooks also suggest that *W = mg* follows ‘naturally’ from the equation *F = ma*. They do look similar so you can see why some might think this, but if you apply that thinking to a book on a table then its weight should be zero because it’s not accelerating.

* **Last night I dreamed that I was weightless. I was like, 0mg !**
* *Why diet? Visit the moon and lose weight!*

**Mandatory Experiments**

* To show that the acceleration of a body is proportional to the force acting on it.
* To verify the principle of conservation of momentum.

**Leaving Cert Physics Syllabus**

|  |  |  |  |
| --- | --- | --- | --- |
| **Content** | **Depth of Treatment** | **Activities** | **STS** |
|  |  |  |  |
| 1.Newton’s laws of motion | Statement of the three laws. | Demonstration of the three laws using air track *or* tickertape timer etc. | Applications:   * seat belts * rocket travel.   Sports, all ball games. |
|  |  |  |  |
|  | Force and momentum: definitions and units. Vector nature of forces to be stressed.  F = ma as a special case of Newton’s second law.  Friction: a force opposing motion. | Appropriate calculations. | Important of friction in everyday experience, e.g. walking, use of lubricants etc. |
|  |  |  |  |
| 2. Conservation of momentum | Principle of conservation of momentum. | Demonstration by any one suitable method.  Appropriate calculations. | Collisions (ball games), acceleration of spacecraft, jet aircraft. |

You don’t have to know this, but I think that it is really, really cool:

**To show how *Newton’s third law of motion* leads to the *principle of conservation of momentum***

**Let’s look at a scenario where one trolley (Trolley 1) which crashes into another (Trolley 2).**

**Let F1 represent the force Trolley 1 exerts on Trolley 2 and let F2 represent the force Trolley 2 exerts on Trolley 1**

**From Newton’s Third Law of Motion:**

F1 = - F2

m1a1 = - m2a2

m1 (v1 – u1)/t = - m2 (v2 – u2)/t

m1v1 – m1u1 = - m2v2 + m2u2

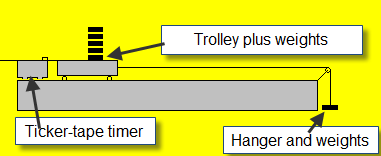
m1v1 + m2v2 = m1u1 + m2u2

**TO SHOW THAT ACCELERATION IS PROPORTIONAL TO THE FORCE WHICH CAUSED IT**

**APPARATUS**

Set of weights, electronic balance, trolley, ticker-tape timer and tape.

**DIAGRAM**



**PROCEDURE**

1. Set up the apparatus as shown in the diagram.
2. Start by taking one weight from the trolley and adding it to the hanger at the other end.
3. Note the weight at this end (including the weight of the hanger) using an electronic balance.
4. Release the system which allows the trolley to accelerate down the track.
5. Use the ticker-tape timer to calculate the acceleration.
6. Repeat these steps about seven times, each time taking a weight from the trolley and adding it to the other end.
7. Record the results for force and acceleration in a table.
8. Draw a graph of Force (on the y-axis) against acceleration (on the x-axis). The slope of the graph corresponds to the mass of the system (trolley plus hanger plus all the weights)

**RESULLTS**

|  |  |
| --- | --- |
| Force  (N) | Acceleration (m s-2) |
|  |  |
|  |  |
|  |  |
|  |  |

**CONCLUSION**

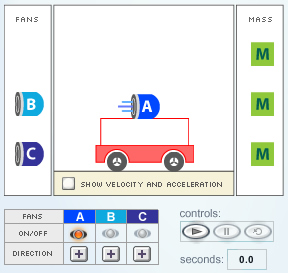
Our graph resulted in a straight line through the origin, verifying that the acceleration is proportional to the force, as the theory predicted.

The slope of our force-acceleration graph was 0.32, which was in rough agreement with the mass of the system which we measured to be 0.35 kg.

**PRECAUTIONS / SOURCES OF ERROR**

1. When adding weights to the hanging masses, you *must* take them from on top of the trolley.
2. Ensure that the runway in smooth, free of dust, and does not sag in the middle.
3. Ensure that the runway is tilted just enough for the trolley to roll at constant speed when no force is applied.

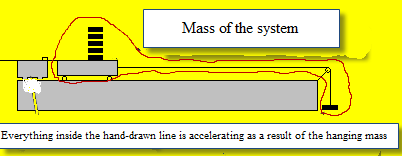
**Investigating the relationship between Force and Acceleration: F =ma**

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|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Displacement –Time** |  | **Velocity -Time** |  | **Acceleration -Time** |
| One Fan |  | One Fan |  | One Fan |
|  |  |  |  |  |
| Two Fans |  | Two Fans |  | Two Fans |
|  |  |  |  |  |
| Three Fans |  | Three Fans |  | Three Fans |

**When must the hanging weights be taken from on top of the trolley?**

**Answer: so that the mass of the system can be kept constant**



We’re looking to investigate the relationship between the acceleration of an object and the force which caused it.

The force which is causing the acceleration is the hanging weights. What mass is accelerating as a result of these weights dropping?

Well obviously the trolley plus the weights sitting on it are accelerating, but not just that; the hanging weights themselves are also accelerating, so the total mass accelerating as a result of the hanging weights is:

trolley + weights sitting on trolley + hanging weights

Now if we’re looking to investigate the relationship between the acceleration of an object and the force which caused it we need to keep all other variables constant. In this case one other variable is the mass which is )being accelerated. The only way to increase the hanging weights while keeping the mass of the system constant, is to transfer weights from the trolley to the hanging weights.

**Using the ticker-tape system**

If using the ticker-tape you will need to calculate the velocity at the beginning (u = s1/ t1), the velocity at the end (v = s2/ t2) and then use the equation v2 = u2 + 2as, where s is the distance between the middle of first set of dots and the middle of the second set of dots.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| s1 (m) | t1(s) | u (m s -1) | s2 (m) | t2(s) | v (m s -1) | s (m) | **a (m s-2)** | **Force**  **(N)** |
|  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |

We pretended that we were using the ticker-tape system, in which case we would need to fill in a table like the one above just to work out the acceleration each time. Because we used a datalogger we didn’t need to do this.

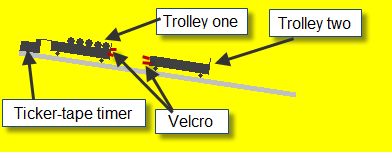
The computer told us what the acceleration was for each run, which made the experiment a lot cleaner and easier to follow.

**TO VERIFY THE PRINCIPLE OF CONSERVATION OF MOMENTUM**

**APPARATUS**

Set of weights, electronic balance, trolley, ticker-tape timer and tape.

**DIAGRAM**



**PROCEDURE**

1. Set up the apparatus as shown in the diagram. The track is tilted slightly so that the trolleys will move at constant velocity when given an initial push.
2. Note the mass of both trolleys to begin with.
3. Both trolleys are initially at rest.
4. Trolley one is given an initial push such that it moves at constant velocity until it collides with Trolley two whereupon they will join together (because of the velcro) and move off as one combined mass
5. Use the ticker-tape to calculate the velocity of Trolley one before the collision and the velocity of the combined mass after the collision.
6. Repeat the experiment a few times, each time adding masses from one trolley to the other .
7. Record the results in the table and for each run calculate the total momentum before and after the collision.

**RESULTS AND CALCULATIONS:**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **MOMENTUM BEFORE** | | | | |  |  | **MOMENTUM AFTER** | | |
|  |  |  |  | **Total Before** |  |  |  | **Total After** |
| m1 | u1 | m1u1 | m2u2 | **m1u1+m2u2** | m2 | (m1 + m2) | v3 | **(m1 + m2)v3** |
|  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |

**CONCLUSION**

After completing the experiment we found that in each case the total momentum before the collision equalled the total momentum after the collision (within the limits of experimental error), in agreement with the theory.

**SOURCES OF ERROR / PRECAUTIONS**

1. Ensure that the runway in smooth, free of dust, and does not sag in the middle.
2. Ensure that the runway is tilted just enough for the trolley to roll at constant speed.

**Notes on the Conservation of Momentum experiment**

**If using the linear air-track**

* In this case friction isn’t an issue and therefore the air-tack should be level.

To see if the track is level check that the trolley doesn’t drift toward either end.

* Block the ten pairs of air holes nearest the buffer end of the track with cellotape. This part of the track will now act as a brake on the vehicle.
* Occasionally check the air holes on the linear air-track with a pin, to clear any blockages due to grit or dust.

**If using the traditional ramp and ticker-tape timer**

* The track is tilted slightly (as in the diagram above) so that the trolleys will move at constant velocity when given an initial push.
* Ignore the first few dots on the tape. These represent where the trolley was being pushed.

**Data-loggers**

We use data-loggers to calculate the velocities because it’s much easier than counting dots on a piece of tape or working out horrendous amounts of calculations associated with the light-gates and air-track. However since the examiners expect old-fashioned answers, we will pretend that we used the ticker-tape.

**Sample results using the data-logger**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **MOMENTUM BEFORE** | | | | |  |  | **MOMENTUM AFTER** | | |
|  |  |  |  | **Total Before** |  |  |  | **Total After** |
| m1 | u1 | m1u1 | m2u2 | **m1u1+m2u2** | m2 | (m1 + m2) | v3 | **(m1 + m2)v3** |
| .25 | .36 | .09 | 0 | **.09** | .25 | .5 | .17 | **.09** |
| .5 | .41 | .205 | 0 | **.21** | .25 | .75 | .26 | **.20** |
| .5 | .55 | .275 | 0 | **.28** | .5 | 1.0 | .28 | **.28** |
| .75 | .45 | .34 | 0 | **.34** | .25 | 1.0 | .34 | **.34** |

**Never let a physics teacher be in charge in a playground**



**Extra Credit**

**\*Isaac Newton**

Something most textbooks are uncomfortable with is the fact that the great Isaac Newton spent over 90 per cent of his time obsessing about alchemy, biblical prophecies and religious disputations, all of which were complete tosh.

The other ten per cent merely changed our view of both science and the universe.

It wouldn’t be too great an exaggeration to say that his scientific research was almost an afterthought.

One noted historian claimed that Newton was not the first great scientist; he was the last of the great mystics.

It seems that Newton died a virgin, and never had so much as a romantic attachment, though he lived to be 84.

**\*What is mass?**

What is the origin of mass? Why do tiny particles have the mass that they do? Why do some particles have no mass at all? At present, there are no established answers to these questions. The most likely explanation may be found in the Higgs boson, a key particle that is essential for the Standard Model to work.

**An invisible problem... What is 96% of the universe made of?**

Everything we see in the universe, from an ant to a galaxy, is made up of ordinary particles. These are collectively referred to as matter, forming 4% of the universe. Dark matter and dark energy are believed to make up the remaining proportion, but they are incredibly difficult to detect and study, other than through the gravitational forces they exert. Investigating the nature of dark matter and dark energy is one of the biggest challenges today in the fields of particle physics and cosmology.

**\*Newton’s Third Law of Motion**

Some other examples:

A balloon flying around the room while deflating.

The movement of a garden hose when it is lying on the ground spraying out water.

The recoil of a rifle could easily shatter a man’s shoulder if not held properly.

The first cannon-ships actually capsized due to the recoil of all the cannons being fired at the same time. Subsequent ships had to be redesigned.

**These are also examples of Conservation of Momentum**

Before the rifle was fired there was no momentum. After the rifle was fired there was the momentum of the bullet going forward (small mass by high velocity) which equalled the momentum of the rifle going backwards (big mass by small velocity). Because they were moving in opposite directions one was positive while the other was negative so their total was again zero.

The same analysis applies to a rocket ship in space firing gas to move. In this case the small mass is the gas going in the opposite direction to the ship. This occasionally gets asked in exams.

**Newton’s Third Law leads to some unusual consequences**

*“To any action there is always an opposite and equal reaction; in other words, the actions of two bodies upon each other are always equal and always opposite in direction”*

If you push against a wall with a force of 20 Newtons, the wall pushes back against you. Seems odd?

Well, think about your book which sits on the table. There is a force pulling it downwards, and yet it doesn’t fall through the table – why not?

There must be an equal and opposite force acting upwards to cause the book to remain at rest. But where can this force come from?

It’s actually the electrons of the atoms on the wall repelling the electrons in the atoms of your book. If you could look at the two surfaces very closely, you would actually see a ‘mesh’ of electrons repelling each other, and the respective surfaces deforming slightly.

While we’re at it may be a good time to also consider the following; An atom is 99.99999% empty space.

Which basically means we are little more than walking, talking, thinking holograms!  
So why does my book, and you, and me (which are all just made up of atoms after all) feel solid?

And for that matter why does it look solid?

Now can you explain how a wall can push back at a force equal to that which you are applying?

So if the wall does push back, why don’t you accelerate backwards?

**\*k = 1 because of how we define the various units: a force of 1 N gives a mass of 1 kg an acceleration of 1 m s-2**

This is also key to why we are stuck with the kilogram as the basic unit of mass. If we are defining the Newton and the m s-2 as the basic units of force and acceleration respectively then F = ma tells us that the m must be the basic unit of mass, which in this case is the kilogram. Now I suppose we could re-name this particular amount of matter and call it one gram (and the kilogram would be another name for a tonne), and if we were starting out again I suppose that’s what we would do, but we’re not starting from scratch and it would just be too confusing to change things at this stage.

**Moment and Momentum: Origin of Terms**

Contraction of \*movimentum, from movere "to move."

Notion of a particle so small it would just "move" the pointer of a scale led to sense of time division, which gave rise to the term *moment of time.*

Still, why *p* for momentum?

Well, Newton thought of "moments" in a more mathematical, abstract sense in the calculus he was inventing (moments of inertia, for example).

In the scientific community at the time Newton published the Principia, \*impetus\* was the quality of an object that was moving independent of an observed force.

Furthermore, the equation p = mv wasn't given first by Newton, but was developed afterwards.

*P* was a convenient symbol - m would be confused with mass, i is too often used to indicate an instance of an object. (Mi usually means the mass of the ith object.)

**Fun Activity**

Get a couple of students to hold up a large sheet (an old bed-sheet will do fine) and get others to throw eggs at it (one at a time) as hard as they can.

The eggs will never break because the sheet deforms on impact, increasing the impact time. Therefore *the rate of change of change of momentum* is less, resulting in a reduced force acting on the egg (from Newton’s Second Law above).

**Ft = (mv – mu)**

This has some serious real-world applications.

All cars have built-in ‘crumple-zones’ which are deliberate weak links in the structure of the car. If the car crashes these sections crumple taking valuable fractions of a second to do, again decreasing the *rate of change* of momentum. So while the car looks worse as a result of this modification, your chances of surviving actually increase.

Google videos of car crashes and car crash tests for more, or as a class activity build your own crumple zones on the front of a trolley to try and stop a nail impaling a plasticine man.

**Terminal Velocity – it’s all about forces**

Another example of a changing force is the air resistance acting on a skydiver in freefall.   
This is roughly proportional to the square of the diver’s velocity, i.e. F ∝ v2.   
As the diver’s velocity increases, so does the air resistance which opposes the motion.   
It is always less than or equal to the gravitational force and so the diver continues to accelerate downwards until the upward air resistance eventually equals (in magnitude) the downward gravitational force. The diver will no longer accelerate at this point but will instead continue at whatever velocity he/she had at the instant that the two forces were equal. This is terminal velocity, and is approximately 100 m/s.

For what it's worth, raindrops also experience terminal velocity.

This also partly explains why clouds (which, being composed of water droplets, and therefore being heavier than air, should fall) remain in the sky. The tiny droplets do accelerate but reach terminal velocity very quickly. In their case terminal velocity is 0.75 cm/sec. In the absence of any other forces, they would therefore continue at this pace, but because these forces are so small they get swamped by the larger forces associated with thermals or the wind, and so simply end up being buffeted about. However if conditions are such that the droplets are allowed to increase in size considerably then the downward force of gravity has a greater affect, and the drops fall as rain.

So there.

**Exam questions**

1. [2004][2006 OL][2008 OL]

Define force.

1. [2008]

Define the newton, the unit of force.

1. [2002 OL]

Copy and complete the following statement of Newton’s first law of motion.

“An object stays at rest or moves with constant velocity \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_”.

1. [2010]

A spacecraft carrying astronauts is on a straight line flight from the earth to the moon and after a while its engines are turned off.

Explain why the spacecraft continues on its journey to the moon, even though the engines are turned off.

1. [2002][2003][2004][2007 OL]

State Newton’s second law of motion.

1. [2006]

State Newton’s third law of motion.

1. [2009]

State Newton’s laws of motion.

1. [2004 OL]

The cheetah is one of the fastest land animals. Calculate the resultant force acting on the cheetah while it is accelerating at a rate of 7 m s-2. The mass of the cheetah is 150 kg.

1. [2004 OL]

Name two forces acting on a cheetah while it is running.

1. [2003 OL][2006 OL]

An astronaut of mass 120 kg is on the surface of the moon, where the acceleration due to gravity is 1.6 m s–2. What is the weight of the astronaut on the surface of the moon?

1. [2006 OL]

Why is the astronaut’s weight greater on earth than on the moon?

1. [2006 OL]

The earth is surrounded by a layer of air, called its atmosphere. Explain why the moon does not have an atmosphere.

1. [2008 OL]

A lunar buggy designed to travel on the surface of the moon (where acceleration due to gravity is1.6 m s-2) had a mass of 2000 kg when built on the earth.

1. What is the weight of the buggy on earth?
2. What is the mass of the buggy on the moon?
3. What is the weight of the buggy on the moon?
4. A powerful rocket is required to leave the surface of the earth.

A less powerful rocket is required to leave the surface of the moon. Explain why.

1. [2002 OL]

The diagram shows the forces acting on an aircraft travelling horizontally at a constant speed through the air.

L is the upward force acting on the aircraft. W is the weight of the aircraft.

T is the force due to the engines. R is the force due to air resistance.

1. What happens to the aircraft when the force L is greater than the weight of the aircraft?
2. What happens to the aircraft when the force T is greater than the force R?
3. The aircraft was travelling at a speed of 60 m s-1 when it landed on the runway. It took two minutes to stop. Calculate the acceleration of the aircraft while coming to a stop.
4. The aircraft had a mass of 50 000 kg. What was the force required to stop the aircraft?
5. Using Newton’s first law of motion, explain what would happen to the passengers if they were not wearing seatbelts while the aircraft was landing.
6. [2003]

If the mass of a skydiver is 90 kg and his average vertical acceleration is 0.83 m s-2,calculate the magnitude and direction of the average resultant force acting on him?

1. [2003]

Use a diagram to show the forces acting on the skydiver and explain why he reaches a constant speed.

1. [2004]

A block of mass 8.0 g moved 2.0 m along a bench at an initial velocity of 2.48 m s-1 before stopping.

What was the average horizontal force exerted on the block while travelling this distance?



1. [2009]

A skateboarder with a total mass of 70 kg starts from rest at the top of a ramp and accelerates down it. The ramp is 25 m long and is at an angle of 200 to the horizontal. The skateboarder has a velocity of 12.2 m s–1 at the bottom of the ramp.

1. Calculate the average acceleration of the skateboarder on the ramp.
2. Calculate the component of the skateboarder’s weight that is parallel to the ramp.
3. Calculate the force of friction acting on the skateboarder on the ramp.
4. What is the maximum height that the skateboarder can reach? (acceleration due to gravity = 9.8 m s–2)
5. Sketch a velocity-time graph to illustrate his motion.
6. [2003]

A person in a wheelchair is moving up a ramp at a constant speed. Their total weight is 900 N.

The ramp makes an angle of 10o with the horizontal.

Calculate the force required to keep the wheelchair moving at a constant speed up the ramp. (You may ignore the effects of friction.)

1. [2007][2002 OL][2006 OL][2009 OL]

What is friction?

1. [2009 OL]

The diagram shows the forces acting on a train which was travelling horizontally.

A train of mass 30000 kg started from a station and accelerated at 0.5 m s−2 to reach its top speed of 50 m s−1 and maintained this speed for 90 minutes.

As the train approached the next station the driver applied the brakes uniformly to bring the train to a stop in a distance of 500 m.

1. Calculate how long it took the train to reach its top speed.
2. Calculate how far it travelled at its top speed.
3. Calculate the acceleration experienced by the train when the brakes were applied.
4. What was the force acting on the train when the brakes were applied?
5. Name the force A and the force B acting on the train, as shown in the diagram.
6. Describe the motion of the train when the force A is equal to the force T.
7. Sketch a velocity-time graph of the train’s journey.

(v = u + at , v2 = u2 + 2as , s = ut + ½at2 , Ek = ½mv2, F = ma )

1. [2007]
2. A car of mass 750 kg is travelling east on a level road. Its engine exerts a constant force of 2.0 kN causing the car to accelerate at 1.2 m s–2 until it reaches a speed of 25 m s–1.

Calculate the net force acting on the car.

1. Calculate the force of friction acting on the car.
2. If the engine is then turned off, calculate how far the car will travel before coming to rest?

**Momentum**

1. [2004][2004 OL][2010 OL]

Define momentum.

1. [2004 OL]

Give the unit of momentum.

1. [2002][2004 OL][2005 OL][2007 OL][2008 OL][2009 OL][2010 OL]

State the principle of conservation of momentum.

1. [2004][2009]

Use Newton’s second law to establish the relationship: force = mass × acceleration.

1. [2007 OL][2010 OL]

A rocket is launched by expelling gas from its engines.

Use the principle of conservation of momentum to explain why a rocket rises.

1. [2003 OL]

What is the momentum of an object with a mass of 5 kg travelling at 10 m s-1?

1. [2007 OL]

Two shopping trolleys each of mass 12 kg are on a smooth level floor.

Trolley A moving at 3.5 m s−1 strikes trolley B, which is at rest.

After the collision both trolleys move together in the same direction.

1. Calculate the momentum of trolley A just before the collision.
2. Calculate the common velocity of the trolleys after the collision.
3. [2004 OL]

The diagram shows a child stepping out of a boat onto a pier.

The boat, which was initially at rest, has a mass of 50 kg.

The child [who was also initially at rest] has a mass of 40 kg and steps out with a velocity of 2 m s−1 towards the pier.

Calculate the velocity of the boat immediately after the child steps out.

1. [2002]

A spacecraft of mass 50 000 kg is approaching a space station at a constant speed of 2 m s-1. The spacecraft must slow to a speed of 0.5 m s-1 for it to lock onto the space station.

1. Calculate the mass of gas that the spacecraft must expel at a speed 50 m s-1 for the spacecraft to lock onto the space station. (The change in mass of the spacecraft may be ignored.)
2. In what direction should the gas be expelled?
3. Explain how the principle of conservation of momentum is applied to changing the direction in which a spacecraft is travelling.
4. [2004]

A pendulum bob of mass 10 g was allowed to swing so that it collided with a block of mass 8.0 g at rest on a bench, as shown. The bob stopped on impact and the block subsequently moved along the bench.

The velocity of the bob just before the collision was 2 m s-1.

Calculate the velocity of the block immediately after the collision.

1. [2008]

A force of 9 kN is applied to a golf ball by a golf club. The ball and club are in contact for 0.6 ms.

Using Newton’s laws of motion, calculate the change in momentum of the ball.

**Mandatory experiments**

**F = ma**

1. [2003 OL]

A student carried out an experiment to investigate the relationship between the force applied to a body and the acceleration of the body. The table shows the measurements recorded by the student.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Force /N | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
| Acceleration /cm s–2 | 8.4 | 17.6 | 25.4 | 35.0 | 43.9 | 51.5 | 60.4 | 70.0 |

1. Draw a labelled diagram of the apparatus used in the experiment.
2. How was the effect of friction reduced in the experiment?
3. Describe how the student measured the applied force.
4. Plot a graph, on graph paper, of the acceleration against the applied force.
5. What does your graph tell you about the relationship between the acceleration of the body and the force applied to it?
6. [2005 OL]

In an experiment to investigate the relationship between force and acceleration a student applied a force to a body and measured the resulting acceleration. The table shows the measurements recorded by the student.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Force /N | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 |
| acceleration /m s–2 | 0.10 | 0.22 | 0.32 | 0.44 | 0.55 | 0.65 | 0.76 |

1. Draw a labelled diagram of the apparatus used in the experiment.
2. Outline how the student measured the applied force.
3. Plot a graph, on graph paper of the acceleration against the applied force.  
    Put acceleration on the horizontal axis (X-axis).
4. Calculate the slope of your graph and hence determine the mass of the body.
5. Give one precaution that the student took during the experiment.

**Principle of conservation of momentum**

1. [2006 OL]

In a report of an experiment to verify the principle of conservation of momentum, a student wrote the following:

I assembled the apparatus needed for the experiment. During the experiment I recorded the mass of the trolleys and I took measurements to calculate their velocities. I then used this data to verify the principle of conservation of momentum.

1. Draw a labelled diagram of the apparatus used in the experiment.
2. How did the student measure the mass of the trolleys?
3. Explain how the student calculated the velocity of the trolleys.
4. How did the student determine the momentum of the trolleys?
5. How did the student verify the principle of conservation of momentum?
6. [2005]

In an experiment to verify the principle of conservation of momentum, a body A was set in motion with a constant velocity. It was then allowed to collide with a second body B, which was initially at rest and the bodies moved off together at constant velocity.

The following data was recorded.

Mass of body A = 520.1 g

Mass of body B = 490.0 g

Distance travelled by A for 0.2 s before the collision = 10.1 cm

Distance travelled by A and B together for 0.2 s after the collision = 5.1 cm

1. Draw a diagram of the apparatus used in the experiment.
2. Describe how the time interval of 0.2 s was measured.
3. Using the data calculate the velocity of the body A before and after the collision.
4. Show how the experiment verifies the principle of conservation of momentum.
5. How were the effects of friction and gravity minimised in the experiment?

**Exam solutions**

1. A Force is anything which can cause an object to accelerate.
2. A force of 1 N gives a mass of 1 kg an acceleration of 1 m s-2.
3. Newton’s first law of motion states that an object stays at rest or moves with constant velocity *unless an external force acts on it*.
4. There are no external forces acting on the spacecraft so from Newton’s 1st law of motion the object will maintain its velocity.
5. Newton’s Second Law of Motion states that the rate of change of an object’s momentum is directly proportional to the force which caused it, and takes place in the direction of the force.
6. Newton’s First Law of Motion states that every object will remain in a state of rest or travelling with a constant velocity unless an external force acts on it.
7. Newton’s laws of motion: see above
8. F = ma ⇒ F = 150 × 7 = 1050 N
9. Gravity (or weight), friction, air resistance.
10. W = mg = 120 × 1.6 = 192 N.
11. Because acceleration due to gravity is greater on the earth (because the mass of the earth is greater than the mass of the moon).
12. Because gravity is less on the moon.
14. W = mg = 2000 × 9.8 = 19600 N
15. 2000 kg
16. W = mg = 2000 × 1.6 = 3200 N
17. The force of gravity is less on moon so less force is needed to escape.
18. It accelerates upwards.
19. It accelerates forward.
20. v = u + at  0 = 60 + a (120)  a = - 0.5 m s-2
21. F = ma  F = 50 000 × 0.5 = 25 000 N.
22. They would continue to move at the greater initial velocity and so would be ‘thrown’ forward.
23. F = ma = 90 × 0.83 = 75 N Down
24. Weight acting down.

Air resistance / friction / buoyancy acting up.

Air resistance = weight, therefore resultant force = 0

Therefore acceleration = 0

1. v2 = u2 + 2as ⇒ 0 = (2.48)2 + 2a(2)

a = 1.56 m s-2

F = ma = (0.008)(1.6) = 0. 0.013 N

1. v2= u2 + 2as ⇒ (12.2)2 = 0 +2a(25) ⇒ a = 2.98 m s–2
2. W = mgsinθ = mgsin20 = 234.63 N
3. Force down (due to gravity) – Resistive force (due to friction) = Net force

Force down (due to gravity) = 234.63 N

Net force= 70(2.98) = 208.38 N

Friction force = 234.63 – 208.38 = 26.25 N

1. v2= u2 + 2as ⇒ u2 = 2g(s) ⇒ s = 5.63 m
2. Graph: velocity on vertical axis, time on horizontal axis, with appropriate numbers on both axes.
3. If the wheelchair is moving at constant speed then the force up must equal the force down, so to calculate the size of the force up, we just need to calculate the force down:

F = mg Sinθ

= 900 Sin 10o

= 156.3 N

1. Friction is a force which opposes the relative motion between two objects.
2. v = u + at

50 = 0 + 0.5t

t = 50/0.5 = 100 s

1. s = ut + ½ at2 (but a = 0)

s = 50 × (90×60) = 270000 m

1. v2 = u2 + 2as

0 = 502 + 2a(500)

a = −2500/1000 = − 2.5 m s-1

1. F = ma

F = 30000× (−)(2.5) = - 75000 N = 75 kN

1. A = friction/retardation / resistance to motion

B = weight / force of gravity

1. The train will move at constant speed.
2. See diagram
3. Fnet = ma = (750)(1.2) = 900 N east.
4. Fnet = Fcar - Ffriction

900 = 2000 - Ffriction  Ffriction = 1100 N west

1. Friction causes deceleration: a = F ÷ m

a = (-1100) ÷ 750 = - 1.47 ms-2

v 2 = u 2 + 2as

0 = 25 +2(-1.47) s or s = 213 m

**Momentum**

1. Momentum is the defined as the product of mass multiplied by velocity.
2. The unit of momentum is the kg m s-1
3. The principle of conservation of momentum states that in any collision between two objects, the total momentum before impact equals total momentum after impact, provided no external forces act on the system.
4. From Newton II: Force is proportional to the rate of change of momentum

F ∝ (mv – mu)/t F ∝ m(v-u)/t F ∝ ma F = k (ma) F = ma

1. The gas moves down (with a momentum) causing the rocket to move up (in the opposite direction with an equal momentum)
2. Momentum = mass × velocity = 5 × 10 = 50 kg m s-1.
3. (*mu* = ) 12 × 3.5 = 42 kg m s-1
4. Momentum before = Momentum after

42 = m3v3 ⇒ v3 = 42/m3 ⇒ *v* = 42/24 = 1.75 ( m s-1)

1. m1u1 + m2u2 = m1v1 + m2v2 ⇒ 0 = (40)(2) + (50)x

⇒ x = - 1.6 m s-1.

1. m1u1 + m2u2 = m1v1 + m2v2

(50000 × 2) = (50000 × 0.5) + (50*m)*

m =1500 kg

1. In what direction should the gas be expelled?

Forward (toward the space station).

1. Explain how the principle of conservation of momentum is applied to changing the direction in which a spacecraft is travelling.

As the gas is expelled in one direction the rocket moves in the other direction.

1. m1u1 + m2u2 = m1v1 + m2v2

(0.01)(2) = (0.008) v2

v2= 2.5 m s-1

1. From Newton II: Force ∝ rate of change of momentum

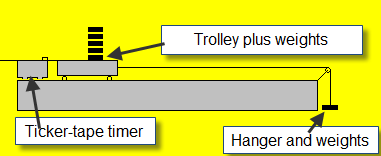
F ∝ (mv – mu)/t

F = (mv – mu)/t {proportional constant = 1}

(mv – mu) = F × t = (9 × 103)( 0.6 × 10-3) = 5.4 kg m s-1.

****

**Mandatory experiments**

1. 
2. See diagram in next question.
3. Tilt the runway slightly, oil the track.
4. By weighing the masses and hanger on an electronic balance.
5. See graph
6. Acceleration is directly proportional to the applied force.
7. See diagram.
8. Outline how the student measured the applied force.

The applied force corresponds to the weight of the hanger plus weights; the value of the weights is written on the weights themselves.

1. Plot a graph, on graph paper of the acceleration against the applied force. Put acceleration on the horizontal axis (X-axis).

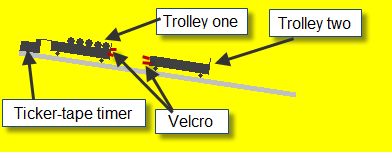
See graph.



1. 

Substituting in two values (from the graph, not the table) should give a slope of approximately 0.9.

This means that the mass = 0.9 kg.

1. Oil the trolley wheels, dust the runway, oil the pulley.
2. See diagram
3. By using an electronic balance.
4. By taking a section of the tape and using the formula velocity = distance/time. We measured the distance between 11 dots and the time was the time for 10 intervals, where each interval was 1 50th of a second.
5. Using the formula *momentum = mass × velocity.*
6. By calculating the total momentum before and afterwards and showing that the total momentum before = total momentum after.
7. See diagram
8. It corresponded to 10 intervals on the ticker-tape.
9. Velocity before: v = s/t = 0.101/0.2

v = 0.505 m s-1  ≈ 0.51 m s-1

Velocity after: v = 0.051/0.2

v = 0.255 m s-1 ≈ 0.26 m s-1

1. Momentum before:

p = mv = (0.5201)(0.505) = 0.263 ≈ 0.26 kg m s-1

Momentum after:

p = mv = (0.5201 + 0.4900)(0.255)

p = 0.258 ≈ 0.26 kg m s-1

Momentum before ≈ momentum after

1. Friction: sloped runway // oil wheels or clean track

Gravity: horizontal track // frictional force equal and // tilt track so that trolley moves with constant velocity

**Fun activities**

**Inertia**

* Stab through a potato with a drinking straw
* Pull table-cloth from under a table of cups, plates etc

**Friction**

Pull apart interleaved books

**Newton’s first law**

* Air-track / air hockey table

**Newton’s third law / conservation of momentum**

* PASCO Runway: first trolley crashes into second. If they are of equal mass then the first stops and the second moves off with the momentum the first trolley had originally.

Question: why don’t they both move with half the original momentum each?

* Get the class to press on top of one hand with the other hand; feel the desk pushing back - equal and opposite!  
  Question: are they the same *type* of force(s)?
* Attach a short piece of tubing to a water tap.

As the water gushes out, the tube moves backward (relate to firefighters)

* Balloon-powered cars or helicopters
* Two students on skates pushing against each other
* One student on skates throwing a medicine ball
* Hover football
* Hovercraft

Small scale: hovercraft made from old CDs and sports caps (or you can buy them cheaply from d’internet).

Large scale: platform and leaf-blower.

YouTube: see fireman using water as hovercraft.

* Student on a trolley with fire extinguisher (try to get low-friction wheels)
* Student on a skateboard pushing off a wall
* Discussion**:** why don't we all fall through the floor?

**Impulse = Ft = (mv – mu)**

Throwing Eggs

Fire the eggs at a loose sheet (held vertically by two students – outside!).

Bottom of the sheet is rolled up to catch the eggs.

Result: eggs don’t break!

Why not?

Risk: take care when throwing the eggs!

**Falling balls**

Drop each golf ball and a basketball separately onto the floor.

Now hold the smaller ball on top of the larger one and release both at the same time

Be careful – the golf ball could fly off in any direction at speed!

**Comment exam mistakes – can you spot the mistake?**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Incorrect answer** | **Incorrect answer** | **Incorrect answer** |
| **Mass** | Amount of matter in an object |  |  |
| **Newton** | The unit of force | The force required to give a mass of 1 kg a velocity of 1 m/s | The force required to give a mass of 1 kg an acceleration of 1 m/s |
| **Newton’s first law** | An object will move at constant speed unless an external force acts on it. |  |  |