# Newton's Laws 1

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# First, a problem!

A car of mass 1000 kg pulls a caravan of mass 800 kg; the driving wheels of the car exert a force of 8000 N on the road, and the total resistance to motion is 3000 N.

What is the

1. net force?
2. acceleration?
3. force of the car on the caravan?

# Lesson Objectives

1. To be able to state Newton's 3 laws of motion.
2. To begin to develop an intuitive understanding of Newton's laws.
3. To learn how to solve problems involving (mainly) the second law.

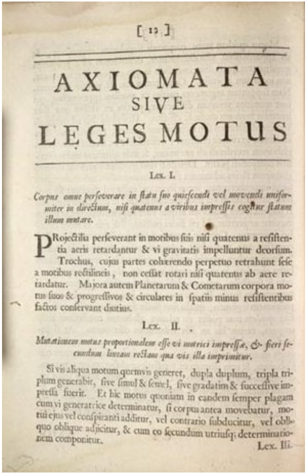
*Textbook pp. 132–137*

# Specification Requirement

*Knowledge and application of the three laws of motion in appropriate situations. For constant mass,* $F = ma$.

[AQA GCE AS and A Level Specification Physics A, 2009/10 onwards]

# Newton's First Law



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AXIOMATA
SIVE
LEGES MOTUS

Lex. I.

*Corpus omne perſeverare in ſtatu ſuo quieſcendi vel movendi uniformiter in directum, niſi quatenus a viribus impreſſis cogitur ſtatum illum mutare.*

PRojectilia perſeverant in motibus ſuis niſi quatenus a reſiſtentia aeris retardantur & vi gravitatis impelluntur deorſum. Trochus, cujus partes cohærendo perpetuo retrahunt ſeſe a motibus rectilineis, non ceſſat rotari niſi quatenus ab aere retardatur. Majora autem Planetarum & Cometarum corpora motus ſuos & progreſſivos & circulares in ſpatiis minus reſiſtentibus factos conſervant diutius.

Lex. II.

*Mutationem motus proportionalem eſſe vi motrici impreſſæ, & fieri ſecundum lineam rectam qua vis illa imprimitur.*

Si vis aliqua motum quemvis generet, dupla duplum, tripla triplum generabit, ſive ſimul & ſemel, ſive gradatim & ſucceſſive impreſſa fuerit. Et hic motus quoniam in eandem ſemper plagam cum vi generatrice determinatur, ſi corpus antea movebatur, motui ejus vel conſpiranti additur, vel contrario ſubducitur, vel obliquo oblique adjicitur, & cum eo ſecundum utriuſq; determinationem componitur.

Lex. III.

*Lex I: Corpus omne perseverare in statu suo quiescendi vel movendi uniformiter in directum, nisi quatenus a viribus impressis cogitur statum illum mutare.*

Philosophiæ Naturalis Principia Mathematica,
Isaac Newton, 1687

# Newton's First Law

*Every body perserveres in its state of rest or in uniform motion in a right line unless it is compelled to change that state by forces impressed upon it.*

- Not a unique idea (Galileo and Descartes)
- Only works in an inertial frame i.e. one that isn't accelerating
- Often referred to as the **law of inertia**

# Newton's Second Law

> *The alteration of motion is ever proportional to the motive force impress'd; and is made in the direction of the right line in which that force is impress'd.*

The second version below is a modern version stating what Newton meant by how he used his terminology (this is how he understood the second law and intended it to be understood).

> *The change of momentum of a body is proportional to the impulse impressed on the body, and happens along the straight line on which that impulse is impressed.*

We could write

$$F = \frac{\Delta(mv)}{t}.$$

# Newton's Second Law

We have just seen that Newton's second law can be written as

$$F = \frac{\Delta(mv)}{t},$$

and if mass is constant (as it will be in the examples we shall consider today), this is the same as

$$\begin{aligned} F &= m\frac{\Delta v}{t} \\ &= ma. \end{aligned}$$

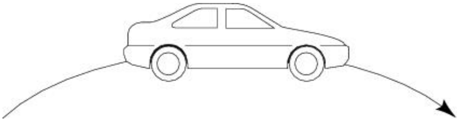
# Health warning (for physicists and mathematicians)!

| | *True always* | *False in general (true only at low velocities)* |
|---|---|---|
| Force | $\mathbf{F} = \frac{d\mathbf{p}}{dt}$ | $\mathbf{F} = m\mathbf{a}$ |
| Momentum | $\mathbf{p} = \frac{m\mathbf{v}}{\sqrt{1 - v^2/c^2}}$ | $\mathbf{p} = m\mathbf{v}$ |
| Energy | $E = \frac{mc^2}{\sqrt{1 - v^2/c^2}}$ | $E = \frac{1}{2}mv^2(+mc^2)$ |

# Some quick problems on laws 1 & 2...

A car rounds a curve while maintaining a constant speed. Is there a net force on the car as it rounds the curve?

1. No – its speed is constant.
2. Yes.
3. It depends on the sharpness of the curve and the speed of the car.



# Some quick problems on laws 1 & 2...

You may have heard the statement "Friction opposes motion". This statement is

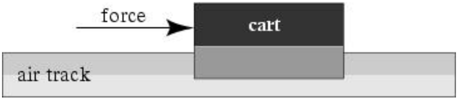
1. hogwash.
2. true.
3. true in some cases, false in others.

# Some quick problems on laws 1 & 2...

A constant force is exerted for a short time interval on a cart that is initially at rest on an air track. This force gives the cart a certain final speed. The same force is exerted for the same length of time on another cart, also initially at rest, that has twice the mass of the first one. The final speed of the heavier cart is

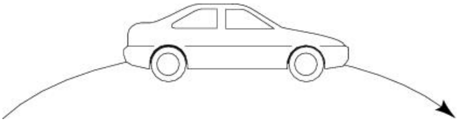
1. one-fourth
2. four times
3. half
4. double
5. the same as

that of the lighter cart.



You are a passenger in a car and not wearing your seat belt. Without increasing or decreasing its speed, the car makes a sharp left turn, and you find yourself colliding with the right-hand door. Which is the correct analysis of the situation?

1. Before and after the collision, there is a rightward force pushing you into the door.
2. Starting at the time of collision, the door exerts a leftward force on you.
3. Both of the above.
4. Neither of the above.



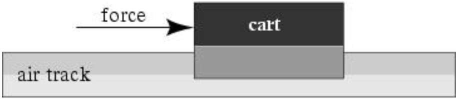
# Some quick problems on laws 1 & 2...

A constant force is exerted on a cart that is initially at rest on an air track. Friction between the cart and the track is negligible. The force acts for a short time interval and gives the cart a certain final speed.

To reach the same final speed with a force that is only half as big, the force must be exerted on the cart for a time interval

1. four times as long as
2. twice as long as
3. equal to
4. half as long as
5. a quarter of

that for the stronger force.



# Newton's Third Law

*To every action there is always an equal and opposite reaction: or the forces of two bodies on each other are always equal and are directed in opposite directions.*

- If body A exerts a force on body B, B will exert an equal and opposite force on A.
- Don't have to be direct contact forces, e.g. gravity!
- Action-reaction forces always occur in 'third-law' pairs.
- The forces act on *different* bodies!

# Newton's Third Law Example: a rocket

A rocket works by pushing hot gases out of the back end at very high speed. The rocket exerts a force on these gases, and the gases push back on the rocket in the opposite direction with a thrust force $T$.

At launch when the rocket is accelerating upwards, the 'ejected gas reaction force' or 'thrust' $T$ must be bigger than the weight $mg$ and so the rocket experiences an unbalanced upward force of $T - mg$.

We can then use Newton's Second Law to find the acceleration:

$$T - mg = ma.$$

# Newton's Third Law and Conservation of Momentum

Consider Newton's Third Law again:

> *For any* **change in momentum** *there is always an equal and opposite* **change in momentum** *in the other direction.*

...or put simply, the total change in momentum of the whole system (all objects in the interaction) is zero.

Newton himself realized this, and derived the law of Conservation of Momentum (which is physically the deeper and more fundamental version of Newton 3) in the *Principia.*

# Some quick problems on (mainly) law 3

Consider a (relatively light) electron orbiting a (much more massive) proton in a hydrogen atom. The force that the electron exerts on the proton is . . . the force the proton exerts on the electron.

1. greater than
2. equal to
3. less than

# Some quick problems on (mainly) law 3

A locomotive pulls a series of wagons. Which is the correct analysis of the situation?

1. The train moves forward because the locomotive pulls forward slightly harder on the wagons than the wagons pull backward on the locomotive.
2. Because action always equals reaction, the locomotive cannot pull the wagons-the wagons pull backward just as hard as the locomotive pulls forward, so there is no motion.
3. The locomotive gets the wagons to move by giving them a tug during which the force on the wagons is momentarily greater than the force exerted by the wagons on the locomotive.
4. The locomotive's force on the wagons is as strong as the force of the wagons on the locomotive, but the frictional force on the locomotive is forward and large while the backward frictional force on the wagons is small.
5. The locomotive can pull the wagons forward only if it weighs more than the wagons.

# Some quick problems on (mainly) law 3

Consider placing a brick on a relaxed spring. While the brick is accelerating downwards, which of the following is true? The magnitude of the force the brick exerts on the spring is

1. larger than
2. equal to
3. smaller than

the downward weight W of the brick.

# Some quick problems on (mainly) law 3

Consider a car at rest. We can conclude that the downward gravitational pull of Earth on the car and the upward contact force of Earth on it are equal and opposite because

1. the two forces form an interaction pair.
2. the net force on the car is zero.
3. neither of the above

the downward weight W of the brick.