How Fast Can Things Go?

Reference: Heinemann Physics 12 4th Edition Chapters 5 – 7 Pages 147 – 269

M.3 DYNAMICS

Dynamics is the study of the causes of motion, in particular the forces acting on a body.

M.3.1 Types of Force

Forces can be divided into two major categories, field forces (much more on this in the next area of study) and contact forces

Forces that act at a distance are called FIELD FORCES, (gravitational, electrical or magnetic)

Forces created when objects touch are called CONTACT FORCES.

M.3.2 States of Motion

There are three states of motion, they are:

1) object at rest
2) object travelling at constant velocity
3) object undergoing acceleration

M.3.3 Galileo's Law of Inertia (Newton's 1st Law)

An object will remain at rest or in uniform motion in a straight line unless acted upon by a force.

Note 1) this applies in any particular direction.
2) if $F = 0$, $v = \text{constant}$ (may be non zero)

M.3.4 Newton's Second Law

When a constant force acts on a body we notice that the body undergoes constant acceleration. If we change the size of the constant force the size of the acceleration changes, such that $F \alpha a$.

Applying a given force to different objects results in differing accelerations. The property of the object that causes this variation is the mass and we have

$$F = m\,a$$

which strictly speaking should be written as

$$\Sigma F = m\,a$$

Force is a vector and behaves as any vector would.

Units Force has the unit of Newton (N)
mass has the unit of Kilogram (Kg)
acceleration has the unit of ms^{-2}

1 Newton ≈ weight of an apple

Note 1) Direction of a is direction of ΣF
2) If $a = 0$ then $\Sigma F = 0$
3) If $a = 0$ in any direction, then ΣF in that direction = 0

Example A body is acted upon by two forces. 3 N north and 4 N east. If its mass is 6 Kg. What is the acceleration?

Solution

M.3.5 Newton's Third Law

The reaction force leads us to Newton's third law, which states:
If one object exerts a force on another then there is an equal and opposite force (reaction) on the first object by the second. i.e. for every action there is an equal and opposite reaction.

M.3.6 Mass and Weight

Mass is a measure of how much material is contained in an object and is measured in Kg. Weight is a measure of the pull of gravity on an object, it is a force and is measured in N. Mass and weight are not the same thing, however they are related. An object in a gravitational field of strength g feels a force, called weight w, that depends on a property of an object called mass and $w = m\,g$ $(g \approx 9.8 \text{ N Kg}^{-1})$

M.3.7 Friction

A force opposing the motion of a body. e.g. table-floor, car-air
Friction is actually proportional to the normal reaction force. The constant of proportionality being the co-efficient of friction (μ), the value of which depends on the shape, surface area, area of contact, etc.

$$\text{Friction} = \mu N$$

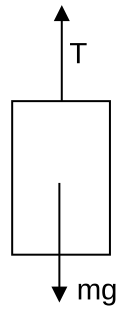
M.3.8 Drawing Force Diagrams

You will often be asked to draw diagrams illustrating forces. There are several considerations when drawing force diagrams:

- The arrows that represent the forces should point in the direction of applied force. The length of the arrow represents the strength of the force, so some effort should be made to draw the arrows to scale.
- An arrow representing a *field force* should begin at the centre of the object.
- An arrow representing a *contact force* should begin at the point on contact where the force is applied.
- All forces should be labelled.

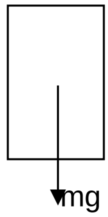
Some sample force diagrams of common situations are drawn below.

Mass on a string



Velocity v = 0, so T = mg
Velocity v = constant upwards, so T = mg
Velocity v = constant downwards, so T = mg
Accelerating Upwards, T - mg = ma.
Acceleration Downwards, mg - T = ma.

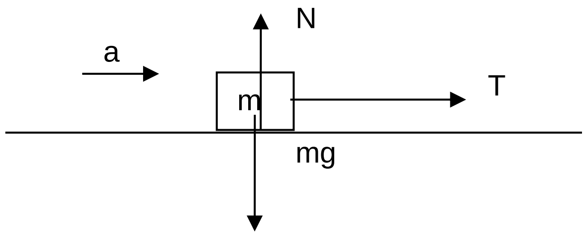
Mass in free flight



$\Sigma F = mg = ma$

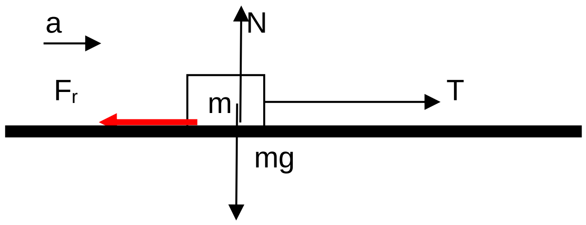
Mass pulled along a plane

Smooth (No Friction)



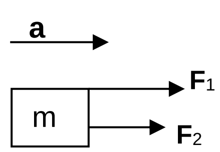
$\mathbf{T} = m\mathbf{a}$, $\mathbf{N} + m\mathbf{g} = 0$

Rough (Friction)

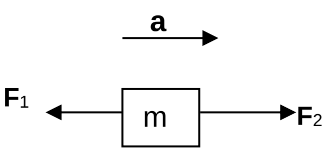


$T - \mathbf{F_{net}} = m\mathbf{a}$, $\mathbf{N} + m\mathbf{g} = 0$

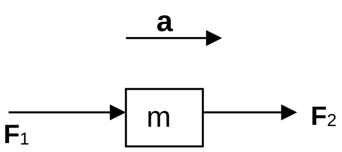
Bodies with parallel forces acting



$F_1 + F_2 = ma$

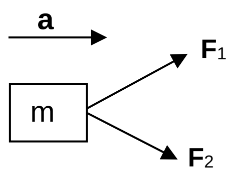


$F_2 – F_1 = ma$

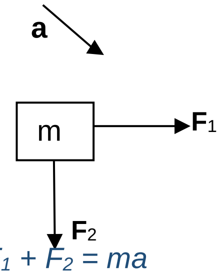


$F_1 + F_2 = ma$

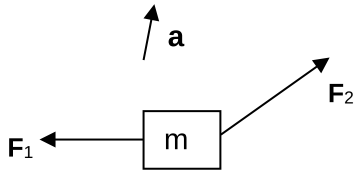
Bodies with non-parallel forces acting



$F_1 + F_2 = ma$



$F_1 + F_2 = ma$



$F_1 + F_2 = ma$

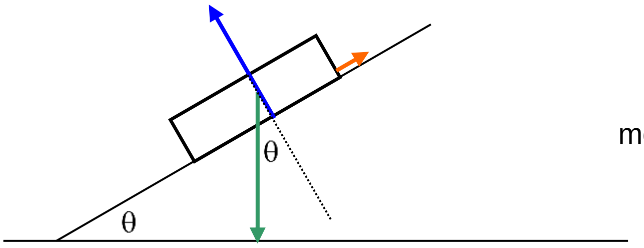
The vectors need to be resolved in order to solve for the acceleration.

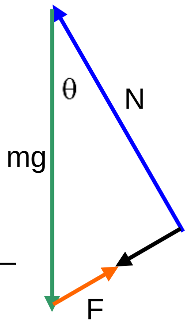
Inclined planes

Another example of forces acting at angles to each other is an object on an incline plane. There are only three different types of examples of a body on an incline plane without a driving force.

A body accelerating

The component of the weight force acting down the plane is larger then the frictional forces. (This is also true if there are no frictional forces). For these situations you would take down the plane to be positive, the reason for this is that the acceleration is down the plane.





Forces perpendicular to the plane

$F_{net} = mg\cos\theta - N$
$= 0$

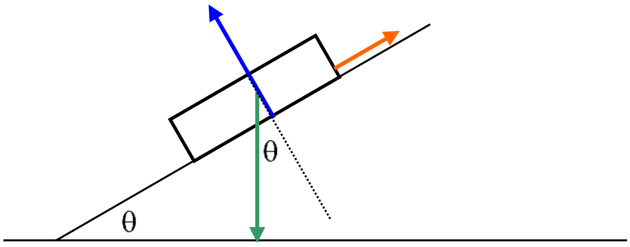
Forces parallel to the plane

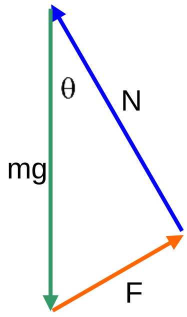
$F_{net} = mg\sin\theta - F$
$= ma$

Thus the acceleration is down the plane. If there is not friction then the acceleration is gsin θ

A body travelling at constant speed

This can be the when an object is not changing its speed whilst travelling down an incline or when the object is at rest on the incline plane.





Forces perpendicular to the plane

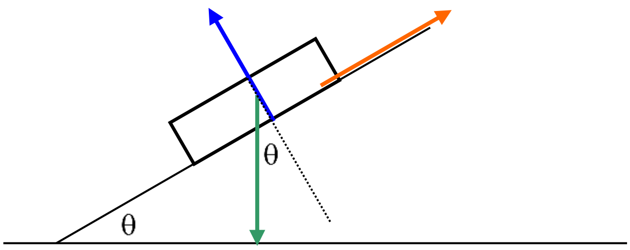
$F_{net} = mg\cos\theta - N$
$= 0$

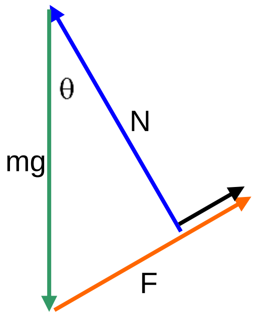
Forces parallel to the plane

$F_{net} = mg\sin\theta - F$
$= 0$

A body decelerating

For these situations you would choose up the plane to be positive, this is because this is the direction of acceleration.





Forces perpendicular to the plane

$F_{net} = mg\cos\theta - N$
$= 0$

Forces parallel to the plane

$F_{net} = F - mg\sin\theta$
$= ma$

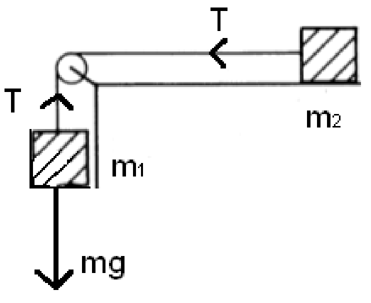
Thus the acceleration is up the plane.

Connected bodies

Problems involving the motion of two bodies connected by strings are solved on the following assumptions;

- the string is assumed light and inextensible so its weight can be neglected and
- there is no change in length as the tension varies.

In these cases, tension is the condition of a body subjected to equal but opposite forces which attempt to increase its length, and tension forces are pulls exerted by a string on the bodies to which it is attached.



To solve these problems you need to consider the vertical direction first.

$m_1g - T = m_1a$

The direction of this acceleration must be downwards.

This leads to: $T = m_1g - m_1a$

The tension in the string is the same in both directions, therefore $T = m_2a$.

Since both bodies are connected by an inextensible string, both bodies must have the same acceleration.

The vertical forces acting on m_2, (not shown) cancel each other out, and do not impact on its motion.

Combing these two equations gives $a = \frac{m_1}{m_1 + m_2}g$ $T = \frac{m_1m_2}{m_1 + m_2}g$
