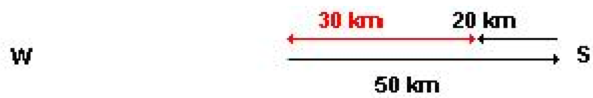
Distance and Displacement

Distance and displacement are different. When you traveled 50 km to the East and then 20 km to the West, the total distance you traveled is 70 km, but your displacement is 30 km East.



In physics, we say that distance is a scalar and displacement is a vector. Scalar has a magnitude and vector has both a magnitude and a direction. Scalar is one dimensional and vector is two dimensional.

Average Velocity and Instantaneous Velocity

Velocity shows how fast an object is moving to which direction. Average velocity can be calculated by dividing displacement over time.

$$V = \frac{\Delta d}{\Delta t} = \frac{displacement}{elapsed\_time}$$

For example, when a car moved 50 km in 2 hours, the average velocity is 25.5 km/h because

$$V = \frac{50km}{2h} = 25.5km/h$$

The instantaneous velocity shows the velocity of an object at one point. For example, when you are driving a car and its speedometer swings to 90 km/h, then the instantaneous velocity of the car is 90 km/h.

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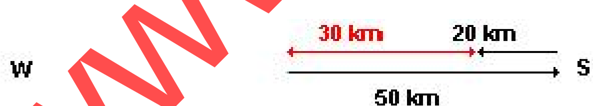

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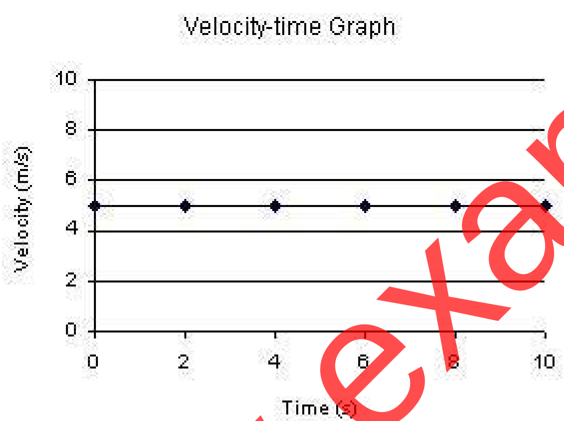
Velocity-time Graph

A velocity-time graph shows the relationship between velocity and time. For example, if a car moves at constant velocity of 5 m/s for 10 seconds, you can draw a velocity-time graph that looks like this:



The area below the line represents the displacement the object traveled since it can be calculated by xy, or (time * velocity) which equals to displacement.

Relative Motion

When the car A is at 50 km/h and the car B is at 30 km/h at opposite direction, the velocity of the car A relative to the car B is 80 km/h.

What is acceleration?

When an object's velocity changes, it accelerates. Acceleration shows the change in velocity in a unit time.

Velocity is measured in meters per second, m/s, so acceleration is measured in (m/s)/s, or m/s2, which can be both positive and negative.

Average Acceleration and Instantaneous Acceleration

The average acceleration is the ratio between the change in velocity and the time interval.

$$a = \frac{\Delta v}{\Delta t} = \frac{Velocity \quad Change}{Ellapsed \quad Time}$$

For example, if a car moves from the rest to 5 m/s in 5 seconds, its average acceleration is

$$a = \frac{5m/s}{5s} = 1m/s^2$$

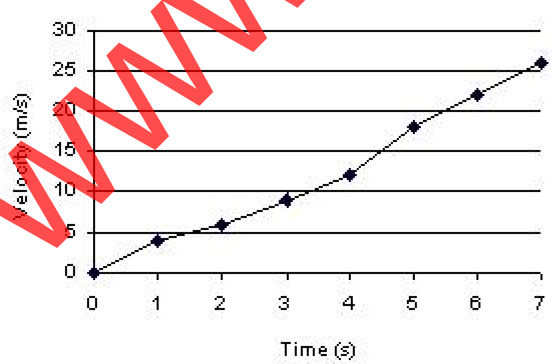
An instantaneous acceleration is the change in velocity at one moment.

More Velocity-time Graph

Let's examine more about a velocity-time graph. We can say that the tangent of a velocity-time graph represents instantaneous acceleration since

$$m = \frac{\Delta y}{\Delta x} = \frac{\Delta V}{\Delta t} = a$$

For example, the instantaneous acceleration when t = 3 at the below graph is 3 m/s2, since the graph has a slope of 3 when t = 3.



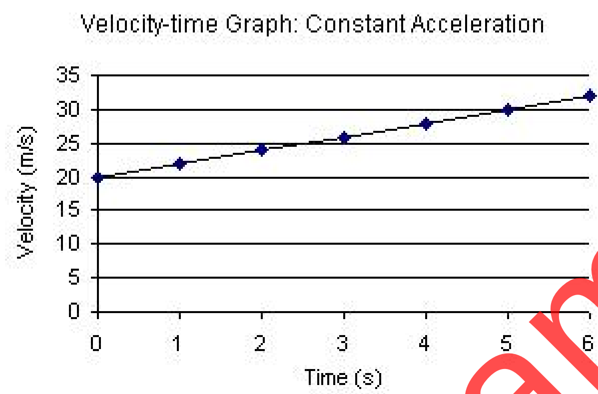
Displacement and Constant Acceleration

In this section, we will assume that acceleration is always constant.

We know that the area under the line of a velocity-time graph represents the displacement. Therefore, the equation

$$d = \frac{1}{2}(V_f + V_i)t$$

is true, where Vi is the initial velocity and Vf is the final velocity, since the area of a triangle is 1/2 * width * height.



The final velocity of a uniformly accelerated object is,

$$V_f = V_i + at,$$

where:

- Vf is the final velocity in m/s,
- Vi is the initial velocity in m/s,
- a is acceleration in m/s2, and
- t is time in second.

Therefore, by substituting it to the previous equation,

$$d = \frac{1}{2}(V_f + V_i)\left(\frac{V_f - V_i}{a}\right) = \frac{(V_f + V_i)(V_f - V_i)}{2a} = \frac{(V_f{}^2 - V_i{}^2)}{2a}$$ therefore,

$$d = V_i t + \frac{1}{2}at^2$$ is true. If you don't understand the derivation, don't worry. The red formulae are the ones that you should learn.

From equations

$$V_f = V_i + at$$

and $$d = \frac{1}{2}(V_f + V_i)t$$,

we can also say that

$$d = \frac{1}{2} \times \frac{[(V_f + V_i)(V_f - V_i)]}{a} = \frac{(V_f{}^2 - V_i{}^2)}{2a}$$

Therefore, $$V_f{}^2 = V_i^2 + 2ad$$ is true. These four red equations are very important and you should be very familiar with them. (It doesn't mean that you should memorize these formulae. Learn by using them.)

Acceleration Due to Gravity

Galileo was the first to find out that all objects falling to Earth have a constant acceleration of 9.80 m/s2 regardless of their mass. Acceleration due to gravity is given a symbol g, which equals to 9.80 m/s2.

Therefore, if you drop a pen, it should behave like this...

Time (s)	Velocity (m/s)	Displacement (m)
0	0	0
1	9.8	4.9
2	19.6	19.6
3	29.4	44.1
4	39.2	78.4

For all previous equations, we can substitute g for a:

$V_f = V_i + gt$

$V_f^2 = V_i^2 + 2gd$

$d = V_i t + \frac{1}{2} g t^2$

What is a Force?

Force can be defined as a push or a pull. (Technically, force is something that can accelerate objects.) For example, when you throw a baseball, you apply a force to the ball. Force is measured by N (Newton). A force that causes an object with a mass of 1 kg to accelerate at 1 m/s is equivalent to 1 Newton.

Newton's First Law of Motion

You will have to learn a new terminology here: net force. Net force is the sum of all forces acting on an object. For example, in a tag of war, when one team is pulling the tag with a force of 100 N and the other with 80 N, the net force would be 20 N at the direction of the first team (100 N - 80 N = 20 N).

When you slide your book on floor it will stop soon. When you slide it on icy surface, it will travel further and then stop. Galileo believed that when you slide a perfectly smooth object on a frictionless floor the object would travel forever.

Isaac Newton developed the idea of Galileo further. He concluded that an object will remain at rest or move with constant velocity when there is no net force acting on it. This is called Newton's First Law of Motion, or Law of Inertia.

Newton's Second Law of Motion

Newton's First Law deals with an object with no net force. Newton's Second Law talks about an object that has net force. It states that when the net force acting on an object is not zero, the object will accelerate at the direction of the exerted force. The acceleration is directly proportional to the net force and inversely proportional to the mass. It can be expressed in formula

F = ma

where:

• F is the net force in N,

• m is the mass of an object in kg and
• a is its acceleration in m/s2.

From this formula, we can say that force is something that accelerates an object.

Newton's Third Law of Motion

When you kick the wall in your room, you will probably end up hurting your foot. Newton's Third Law of Motion can explain why: when one object applies a force on a second object, the second object applies a force on the first that has an equal magnitude but opposite direction. In other words, when you kick the wall, the wall kicks you back with equal force. As a result you will get hurt. These forces are called action-reaction forces.

Remember when you kick the wall, you exerts force on the wall. When the wall kicks you back, it exerts force on you. Therefore, the net force on the wall is not zero and the net force on your foot is not zero neither.

Mass and Weight

Mass and weight are different in physics. For example, your mass doesn't change when you go to the Moon, but your weight does. Mass shows the quantity, and weight shows the size of gravity.

If you know your mass, you can easily find your weight because

W = mg

where:

• W is weight in Newton (N),

• m is mass in kg, and

• g is the acceleration of gravity in m/s2.

If your mass is 70 kg on Earth, your weight is

W=(70 kg)(9.8 m/s2) = 686 N.

Weight is measured by Newton (N).

Friction

You will have to learn another vocabulary before you proceed: the normal force. The normal force acts on any object that touches surface (either directly or indirectly). The normal force would be applied on a ball on a table, but not on a ball in the air, for instance. It always acts perpendicularly to the surface. The formula to calculate the normal force is

FN = - mg

where:

• FN is the normal force in Newton (N),

• m is the mass in kg, and

• g is the gravitational force in m/s2.

For example, the normal force acting on a 70 kg-person would be

FN = - (70 kg)(-9.8 m/s2) = 686N

Now, we will talk about friction.

When you slide your book on floor, it will come to stop because of the force of friction. Friction is the force that acts between two object in contact because of action-reaction.

Force of friction can be calculated by the formula

$$F_f = \mu F_N$$

where:

• Ff is the force of friction in N,
• is the coefficient of friction, and
• FN is the normal force in N.

The value of depends on surface you are dealing with. The following table shows some example of μ.

Surface	**Value of μ**
rubber on dry asphalt	~1
rubber on wet asphalt	0.95
steel on steel	0.18
steel on ice	0.010

rubber on ice	0.005

For example, if you throw a 500 g book on floor where = 0.1, the force of friction would be:

$F_f = \mu F_N = (0.1)(0.5 * 9.8) = 0.49$ N

Simple Breakdown of Forces

You can break down forces into several components easily. For example, the force F1 can be broken into two forces: Fx and Fy.

The following formulas are true:

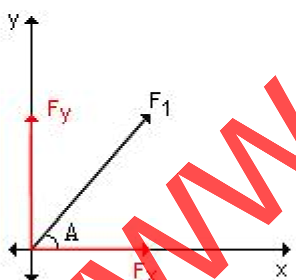
Fx = cos A * F1

Fy = sin A * F1

The idea of "breaking down forces" is very important in this chapter.

Two Dimensional Forces into One

You can combine two forces into one. Suppose Jack pushed a box with a force of 30 N at 0 degree and Michael pushed it with a force of 40 N at 45 degrees. How can we find the net force acting on the box?



The first thing you have to do is to find all forces on x direction (x axis) only. Jack exerts 30 N and Michael exerts (cos 45 * 40) N at x direction. Therefore, the total force on x direction would be

30 N + (cos 45 * 40) N = 58.3 N. [E]

Then, you will have to analyze all forces on y direction (y axis). Since Jack exerts no force and Michael exerts (sin 45 * 40) N, the total force on y direction would be

0 N + (sin 45 * 40) N = 28.3 N. [N]

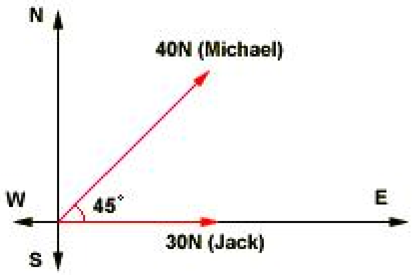
To find the combination of Jack and Michael's forces, we can just combine forces on x and y directions. Therefore, using the Pythagorean Theorem, we can calculate that

$$\sqrt{(58.3)^2 + (28.3)^2} = 64.8\ \mathrm{N}$$

is the magnitude (size) of the combined forces.

One Dimensional Forces into Two

You can also break down forces. For example, Fred pushed a box to the east and Jack pushed it to the north. If the net force is 100 N to north east by 45 degrees,



the force applied by Fred would be

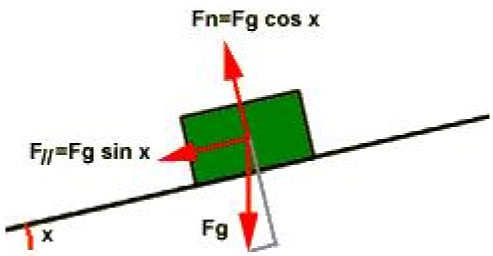
FFred = cos 45 * 100 = 70.7 N

and the force by Jack is

FJack = sin 45 * 100 = 70.7 N

When you combine FN and Fg, a single force that acts parallel to the surface will be generated. This force, called the force of parallel (F//), causes the box to move forward. F// can be calculated by Fg * sin x.

To conclude, the mixture of the force of parallel and the force of friction determines how the box moves. If the force of parallel is larger than the force of friction, the box will slide. If both forces have equal magnitude, the box will not slide. If the force of friction is larger than the force of parallel, the box will move upward. (Just kidding. The force of friction can never be greater than the force of parallel.)



Forces in Three Directions

If you see a mixture of three or more forces like below,

All you have to do is to calculate forces on x direction, on y direction, and add these two forces into one to get the total net force.