EDEXCEL NATIONAL CERTIFICATE/DIPLOMA
SCIENCE FOR TECHNICIANS

OUTCOME 1 - STATIC AND DYNAMIC FORCES

TUTORIAL 1 – BASIC SCIENCE

1 Static and dynamic forces

Forces: definitions of: matter, mass, weight, force, density and relative density; pressure, scalar and vector quantities, vector representation of forces, balanced and unbalanced forces, moments of couples, conditions for equilibrium, parallelogram and triangle of forces, coplanar forces and centre of gravity.

Stress and strain*:* direct stress and strain, shear stress and strain, Hooke's law, modulus of elasticity, load extension graphs

Motion*:* force, velocity and acceleration; action and reaction, Newton's laws of motion, linear and angular motion, momentum

On completion of this tutorial you should be able to:

- Use correct S. I. units and multiples
- Make calculations involving the density of material.
- Define force in terms of mass and acceleration.
- Explain gravity and use the gravitational constant.
- Explain and calculate weight.
- Explain pressure.
- Explain pressure due to the depth of a liquid.
- Explain the relationship between force and pressure.

Worksheet 1 should be completed after doing this tutorial.

1. UNITS AND MULTIPLES

This section is for any student not familiar with or wishing to revise fundamental physical quantities and units.

In Engineering, there are five basic quantities that describe everything we are likely to use. These quantities must have recognised units and symbols. The system used in Britain is the International System of units or S.I. The five quantities are as follows.

Quantity	Unit	Symbol
Mass	kilogramme	kg
Length	metre	m
Time	seconds	s
Temperature	Kelvin	K
Electric current	Amperes	A

Other common quantities are made from a mixture of these basic units and they are usually given a name of their own. For example, the unit of force is a mixture of units called a Newton (After Isaac Newton). The mixture is a kg x m $\div s^2$. Here are the main ones.

Quantity	Quantity Symbol	S.I. Unit	Unit Symbol	Basic Combination
Force	F	Newton	N	kg m/s^2
Energy	E	Joules	J	N m
Work	W	Joules	J	N m
Power	P	Watts	W	N m/s
Pressure	p	Pascal	Pa	N/m^2
Stress	σ	Pascal	Pa	N/m^2
Density	ρ	none	none	kg/m^3
Specific heat	c	none	none	J/kg K
Area	A	none	none	m^2
Volume	V or Q	none	none	m^3
Voltage	V	Volt	none	
Resistance	R	Ohm	Ω	

MULTIPLES

S.I. units are often much too big or much to small to be written in sensible numbers so we use multiples as follows.

NAME	SYMBOL	VALUE	DECIMAL VALUE
Tera	T	10^{12}	1 000 000 000 000
Giga	G	10^9	1 000 000 000
Mega	M	10^6	1 000 000
Kilo	k	10^3	1 000
Basic		1	1
Milli	m	10^{-3}	0.001
Micro	μ	10^{-6}	0.000 001
Nana	n	10^{-9}	0.000 000 001
Pico	p	10^{-12}	0.000 000 000 001

Note that in the S.I. system, the unit of mass is the kg and this is the only quantity that is not normally the base unit. Another rule of the S.I. system is that we should not write numbers larger than 1000 or smaller than 0.1. We should use appropriate multiples instead. The S.I. standard is that multiples of 1000 are preferred throughout.

EXAMPLES OF MULTIPLES

LENGTH	FORCE	VOLTAGE
km = 1000 m	MN = 1000 000 N	MV = 1000 000 V
mm = 0.001 m	kN = 1000 N	kV = 1000 V
		mV = 0.001 V
		μV = 0.000 001 V

Other multiples such as centi and deci can be used with care and these come out in the multiples of volume.

VOLUME

The base unit is the cubic metre	m^3	
1/1000 th of this is a cubic decimetere	dm^3	This is also called a litre
1/1000 1000 th of this is the cubic centimetere	cm^3	This is also called a millilitre
1/1000 000 000 th of this is the cubic millimetre	mm^3	

SELF ASSESSMENT EXERCISE No.1

Express the following in correct S.I. multiples

0.003 m
2000 N
0.004 m^3
6×10^9 N
5×10^{-6} V

Students should make sure that they are familiar with the exponent form of representing numbers and how to use the exponent button on their calculators.

For example to enter 5×10^6 on the calculator you should key in the following.

5 EXP 6 If you press enter this will convert into decimal 5 000 000

DO not key in 5 x 10 EXP –6. If you do then the number returned will be 50 000 000.

DO this sum on your calculator.

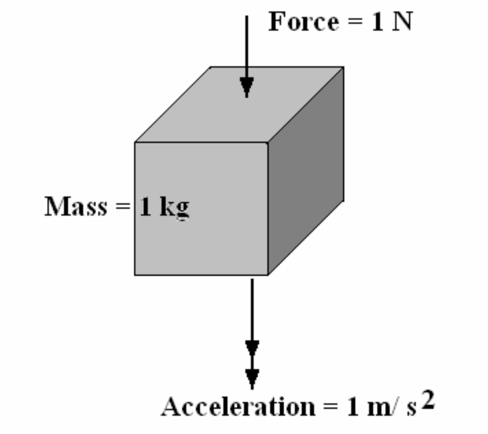
$2 \times 10^6 \times 5 \times 10^{-3}$ = ____________________________

The correct answer should be 10 000 or 10×10^3

2. DEFINITIONS OF PHYSICAL QUANTITIES

2.1 MASS

Mass is the amount of matter in a body. What is matter? Well scientists know that matter is made up of atoms and molecules. A molecule is a combination of two or more atoms not necessarily of the same type. Atoms are made up of sub atomic particles and scientists are still finding new sub atomic particles. The mass of a body depends on the number and types of atoms in it. The basic quantity of mass is the kilogramme. This used to be defined as the mass of 1 dm^3 of water at 0^oC but is now the mass of a standard piece of platinum kept in Paris. Another way of defining mass is by examining the force needed to accelerate or decelerate bodies.



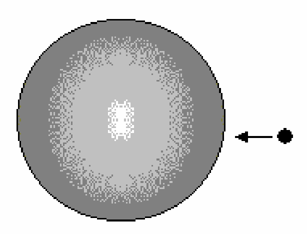
The more mass (or inertia as it is often called), the harder it is to accelerate or decelerate it or make it change its motion in any way. Newton's investigation into this has led to the realisation that it required 1 N force to accelerate 1kg at a rate of 1 m/s^2. In fact there is much discussion about which defines which. Does the mass define the force or does the force define the mass?

If $1N = 1kg \times 1\ m/s^2$ Then it follows that $1kg = 1\ N \div 1\ m/s^2 = 1\ N/\ s^2 m$

This reminds us that a Newton force is a derived unit and is a combination of kilogrammes metres and seconds.

It is difficult to visualise the relationship between force, mass and acceleration because gravity and weight confuse the issue. It is best to imagine the acceleration taking place in outer space or on a flat frictionless surface. Let's look at the gravity next.

2.2 GRAVITY AND WEIGHT



All bodies exert a force of attraction on each other but this force diminishes with distance. Unless one of the bodies is very large and/or very close, the effect is very small. In the case of the Earth, it is large and we are close so it exerts a force of gravity on everything close to it such that any unrestrained body would accelerate downwards towards the centre of the Earth at 9.81 m/s^2.

This is the gravitational constant "g". Galileo showed that large and small bodies fall at the same rate with his famous experiment when he dropped two cannon balls of different sizes from the leaning tower of Pisa. They hit the ground together. This experiment works for compact masses but if you dropped a spanner and a feather, the feather would float around on the air currents.

Astronauts on the moon showed that in the absence of air, a spanner and a feather fall together.

Since all bodies are accelerated downwards at the same rate then the force of gravity acting on every kilogramme is 9.81 N. In order to stop a body falling, an equal and opposite force upwards must be applied. This is usually exerted by the ground on all stationary bodies and gives rise to the idea of weight. The weight of a body is simply the force of gravity acting on it so

Weight = M g.

In simple terms, each kilogramme weighs 9.81 N.

2.3 DENSITY

Density is a very important concept. It is a figure that tells us how many kg of a uniform substance is contained in a volume of 1 m^3. The value for pure water is one of the best-known figures since from the old definition that 1 kg was the mass of 1 dm^3 of water then since there are 1000 dm^3 in a the density must be 1000 kg per m^3.

This is written in engineering as 1000 kg/m^3

In general density is defined as the ratio of mass to volume and is given the symbol ρ (Greek letter rho).

Density = ρ = mass ÷ volume or $\rho = M/V$

You must be able to manipulate the formulae to make either M or V the subject so it follows that

$M = \rho V$ and $V = M/\rho$

RELATIVE DENSITY

Often the density of substances is compared to that of water and this is the relative density. For example Lead has a mass 11.34 larger than the mass of the same volume of water so the relative density is 11.34. The symbol used is d.

Relative density = d = Mass of a substance ÷ Mass of the same volume of water

If we take 1 m^3 as our volume then:

d = Mass of 1 m^3 of the substance ÷ 1000

or d = Density of the substance ÷1000

SELF ASSESSMENT EXERCISE No.2

1. Lead has a density of 11340 kg/m^3. Calculate the volume of 12 kg.
2. Aluminium has a density of 2710 kg/m^3. Calculate the relative density.
3. Seawater has a relative density of 1.036. Calculate the density of sea water.

<u>TABLE OF DENSITIES FOR MATERIALS</u>

Material	Density kg/m^3
Air 20 °C, 1 atm, dry	1.21
Aluminium	2700
Balsa wood	120
Brick	2000
Copper	8900
Cork	250
Diamond	3300
Glass	2500
Gold	19300
Helium (0 °C, 1 atm)	0.178
Hydrogen (0°C, 1 atm)	0.090
Ice	917
Iron	7900
Lead	11300
Mercury	13600
Nickel	8800
Oil (olive)	920
Oxygen (0 °C, 1 atm)	1.43
Platinum	21500
Silver	10500
Styrofoam	100
Tungsten	19300
Uranium	18700
Water 20 °C, 1 atm 20 °C, 50 atm seawater 20 °C, 1 atm	 998 1000 1024

3. PRESSURE

Fluids at rest produce static forces on the surfaces containing them because

- the weight of the fluid acts on them.
- it is compressed and contained by some external force.

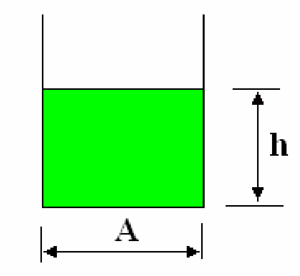
3.1 UNITS OF PRESSURE

Pressure is defined as Force/Area. The basic units are hence N/m^2. This is given the name of a Pascal (Pa). It is a small unit so kPa and MPa are used also. A common unit of pressure is the Bar which is 100 kPa.

1 MPa = 1 000 000 N/m^2. 1 kPa = 1 000 N/m^2. 1 bar = 100 000 N/m^2.

3.2 PRESSURE DUE TO DEPTH

Consider a container full of liquid as shown with density ρ kg/m^3.

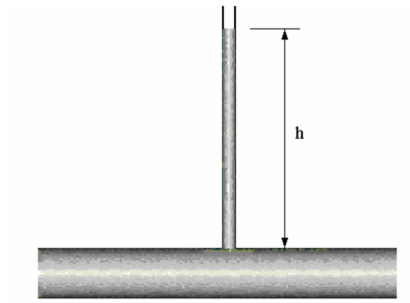


The volume = A h
The mass = ρAh
The weight = gρAh

The force on the bottom of the container is the weight of the liquid.
The pressure on the bottom is the weight per unit area so
p = Weight/Area = ρgh

Note that the pressure depends only on the depth and not on the area.
The pressure of a liquid must act equally in all directions. It will always push normal to a surface. The pressure will be the same at all points at the same depth. These statements are called Pascal's Law.

3.3 PRESSURE HEAD

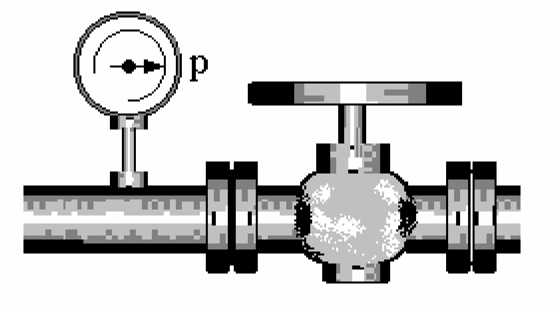


When h is made the subject of the formula, it is called the pressure head. ***h = p/ρg***

Pressure is often measured by using a column of liquid. Consider a pipe carrying liquid at pressure p. If a small vertical pipe is attached to it, the liquid will rise to a height h and at this height, the pressure at the foot of the column is equal to the pressure in the pipe.

3.4 PRESSURE INSIDE PIPES AND VESSELS

Pressure results when a liquid is compacted into a volume. The pressure inside vessels and pipes produce stresses and strains as it tries to stretch the material. An example of this is a pipe with flanged joints. The pressure in the pipe tries to separate the flanges. The force is the product of the pressure and the bore area.



WORKED EXAMPLE No. 1

Calculate the force trying to separate the flanges of a valve (Fig.1.18) when the pressure is 2 MPa and the pipe bore is 50 mm.

SOLUTION

Force = pressure x bore area
Bore area = $\pi D^2/4 = \pi \times 0.05^2/4 = 1.963 \times 10^{-3}\ m^2$
Pressure = 2×10^6 Pa
Force = $2 \times 10^6 \times 1.963 \times 10^{-3} = 3.927 \times 10^3$ N or ***3.927 kN***

WORKED EXAMPLE No. 2

Calculate the pressure and force on an inspection hatch 0.75 m diameter located on the bottom of a tank when it is filled with oil of density 875 kg/m^3 to a depth of 7 m.

SOLUTION

The pressure on the bottom of the tank is found as follows. $p = \rho g h$
$\rho = 875\ kg/m^3$
g = 9.81 m/s2
h = 7 m
$p = 875 \times 9.81 \times 7 = 60086\ N/m^2$ or ***60.086 kPa***
The force is the product of pressure and area.
$A = \pi D^2/4 = \pi \times 0.75^2/4 = 0.442\ m^2$
$F = p A = 60.086 \times 10^3 \times 0.442 = 26.55 \times 10^3$ N or ***26.55 Kn***

SELF ASSESSMENT EXERCISE No.2

1. A mercury barometer gives a pressure head of 758 mm. The density is 13 600 kg/m3. Calculate the atmospheric pressure in bar. (1.0113 bar)

2. Calculate the pressure and force on a horizontal submarine hatch 1.2 m diameter when it is at a depth of 800 m in seawater of density 1030 kg/m^3. (8.083 MPa and 9.142 MN)

3. A compressor has a piston 60 mm diameter and it acts against a gas with a pressure of 5 bar (0.5 MPa). Calculate the force on the piston. (1.41 kN)

4. A pipe 30 mm bore diameter contains water at 4 MPa pressure. Calculate the force trying to stretch the pipe. (2.83 MPa)