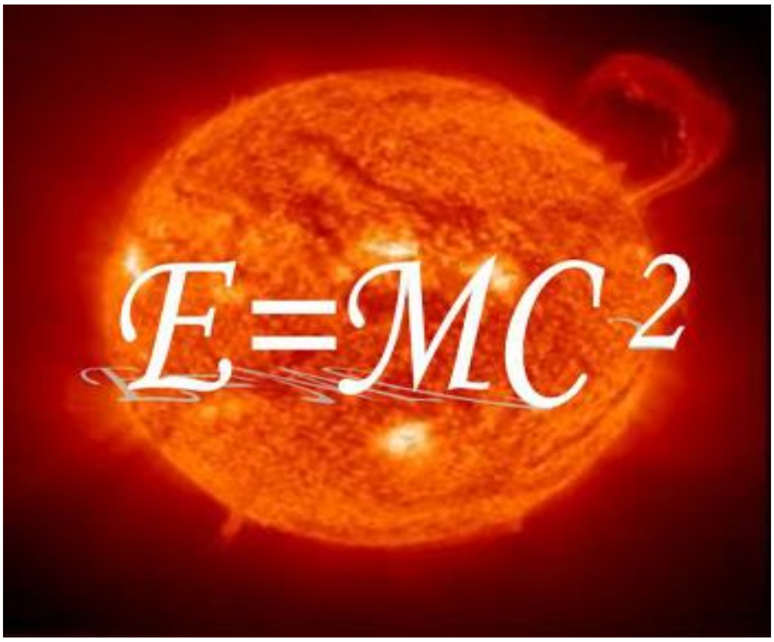
Te Whare Wānanga o te Awakairangi

E

DC fundamentals EE3103

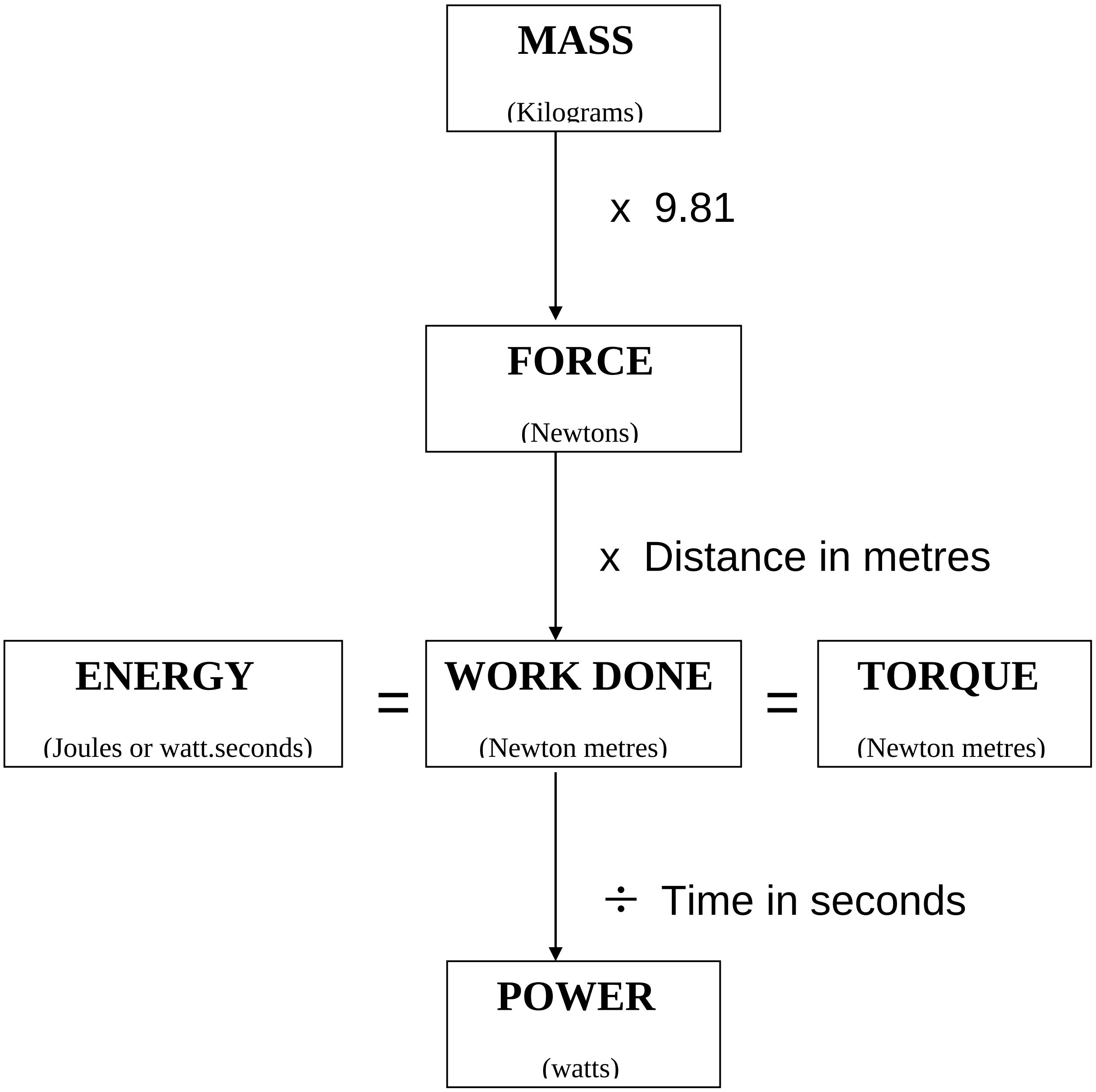
Student workbook calculations

Mechanics part two of two



Student name

Mechanics relationships



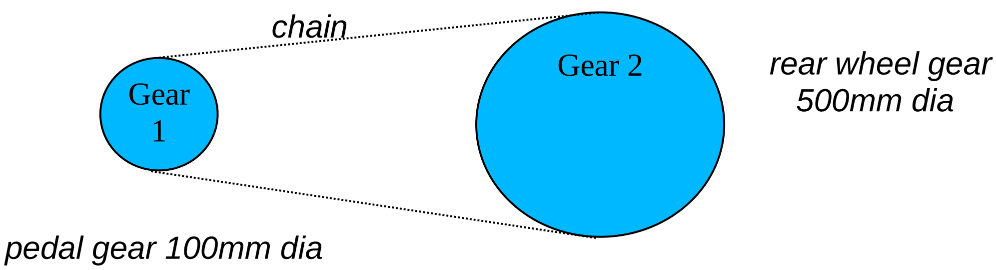
CHANGING GEAR

Shafts , chains and belts transport power from one location to another within the mechanical system.
The attached gears and pulleys have 2 main functions.
Firstly to alter the revolutions per minute (rpm) and surface or circumference speed, and secondly to achieve a mechanical advantage.

Using a 21 speed mountain bike as an illustration of these concepts, consider cycling along a flat road in top gear or gear 21. You have enough power by the virtue of your muscle mass to move along at say 35 km/hr.

A very steep hill looms ahead and you rightly feel that you are not strong (powerful)enough to maintain a speed of 35 km/hr up the increased slope.
You end up "changing down" to gear 3 and find that you are putting in the same effort but now you are travelling along at 5 km/hr.

You required a greater *Force* to "lift" you and the bikes combined mass up the slope and traded extra time to overcome the extra load demands using the same power.



If we calculate how far the chain will travel with one revolution of the pedal gear (your input) we use $\pi D = \pi \times 100\text{mm} = 314\text{mm}$
and calculating the circumference of the rear wheel;

$$\pi D = \pi \times 500\text{mm} = 1570\text{mm}$$

Therefore the rear wheel travelled $\frac{314\text{mm}}{1570\text{mm}} = 0.2$ revolutions in the same time
This means a change of 100 to 500 (1 to 5) results in a speed change of 1 revolution to 1/5 of a revolution.

This illustrates the formula $\frac{D1}{D2} = \frac{N2}{N1}$ $\quad \frac{\textit{input diameter}}{\textit{output diameter}} = \frac{\textit{output rpm}}{\textit{input rpm}}$

And as we saw previously we put in the same power to overcome an increased load by taking more time (ie we lost rpm) we can add rotational effort (torque) into the above equation.

$$\frac{\mathbf{T1}}{\mathbf{T2}} = \frac{\mathbf{D1}}{\mathbf{D2}} = \frac{\mathbf{N2}}{\mathbf{N1}} \qquad \frac{\textit{input torque}}{\textit{output torque}} = \frac{\textit{input diameter}}{\textit{output diameter}} = \frac{\textit{output rpm}}{\textit{input rpm}}$$

JUST A MOMENT

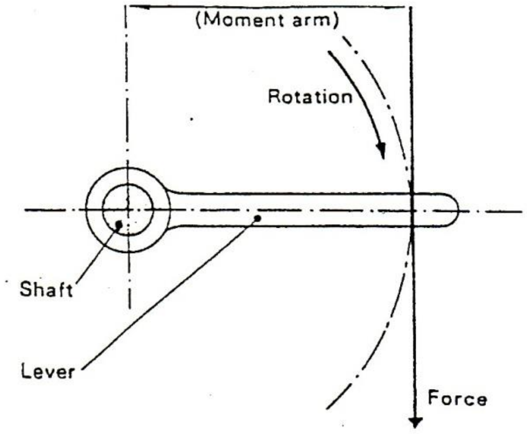
A moment is the turning effect of a force.

A force is measured in *newtons.*
The distance from the turning pivot to where the force is applied is measured in *metres.*
So the result is measured in *Newton.metres*.

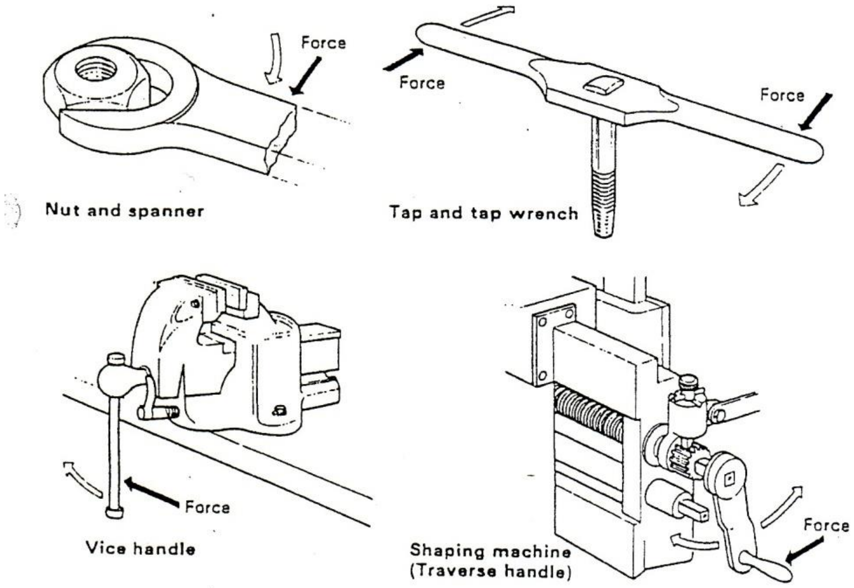
From the formulae sheet we see that **work done = force x distance**
and is also measured in *Newton.metres.*

We also see that $1\ Nm = 1\ J = 1\ kWh$ concluding that a moment is a form of energy, the ability to do work.

Below are some every day examples of a captured moment you will probably have encountered.



Moment – a turning effect



MECHANICS FORMULAE SHEET

To achieve balance **load moment = effort moment**
or **clockwise moment = anticlockwise moment**
and **a moment = force x distance**
or **Torque = force x radius**

Gravity (g) = 9.81N/kg The force to overcome gravity is 9.81N of force for each kg of mass

Force = mass x gravity
F = m x g

Force = mass x acceleration unit of force Newton

Work done = Force x distance unit of work Newton metre or joule
W = F x d

Power = $\frac{\text{work done}}{\text{time}}$ unit watts = $\frac{\text{watt.seconds}}{\text{seconds}}$

$P = \frac{WD}{t}$

and transposed **work = power x time**
W = P x t

Mechanical rotational power = $\frac{2\pi \text{ (rpm) x Torque (Nm)}}{60}$

$$P = \frac{2\pi NT}{60}$$

mechanical power = electrical power
1 hp = 746 watts

electrical energy = mechanical energy = work done
1 watt.second (Ws) = 1 Newton.metre (Nm) = 1 Joule (J)

$\frac{\text{input torque}}{\text{output torque}} = \frac{\text{input pulley diameter}}{\text{output pulley diameter}} = \frac{\text{output rpm}}{\text{input rpm}}$

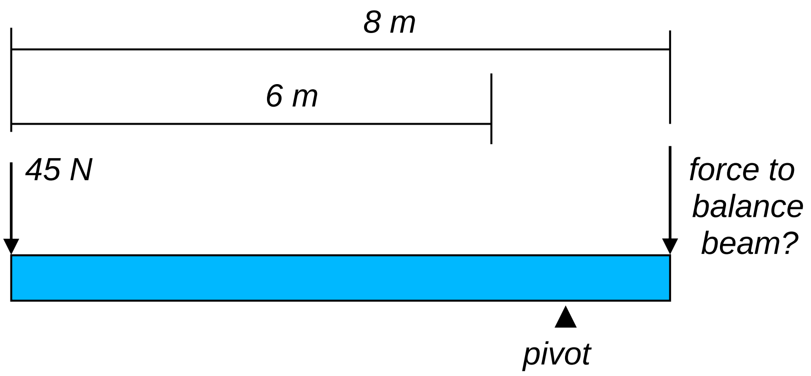
or $\frac{T1}{T2} = \frac{D1}{D2} = \frac{N2}{N1}$

For H2O **1 cubic metre = 1000 litres = 1000kg**
and **1000cc = 1 litre = 1 kg**

WORKED EXAMPLE 1

Question : 45N of force is applied to a beam that is 8m long. The beam is pivoted 6m from this force. What force needs to be applied to the other end to balance the beam.

Firstly, it is a good idea to draw a picture of what is happening to create a visual image, then add information to that as you calculate values, much like putting together a jigsaw puzzle.



To balance the beam we use the formulae

For balance load moment = effort moment

and a moment is a force x the distance from the pivot

applying these concepts we calculate

45 N of force x 6 m = anticlockwise torque

45 x 6 = 270 Nm

and to balance the load (like balancing scales) the other side would need 270Nm

We know the clockwise force is 2m from the pivot so that force x 2m = 270Nm

$$F \times 2\ m = 270\ Nm$$

$$F = \frac{270\ Nm}{2\ m}$$

F = 135 N (force to balance beam)

WORKED EXAMPLE 2

Question: A crane needs to apply a force of 10,000 N to lift a car onto a flat deck truck. What is the mass of the car?

We would need to assume that we are calculating the mass. i.e.: The weight is calculated at sea level on the planet earth.

We would use the formula: Force = Mass x acceleration

and as we are lifting vertically the acceleration part of the equation is gravitational acceleration, known as g and valued at 9.81 m/s^2.

The formula is now modified to

$$\text{Force} = \text{Mass} \times g$$

where Force is in newtons Mass in kg and g = 9.81

The force we used was 10,000N therefore;

$$10{,}000\text{N} = \text{Mass (kg)} \times 9.81$$

and by transposition

$$\frac{10{,}000\text{N}}{9.81} = \text{Mass (kg)}$$

$$\text{Mass} = 1{,}019.38 \text{ kg}$$

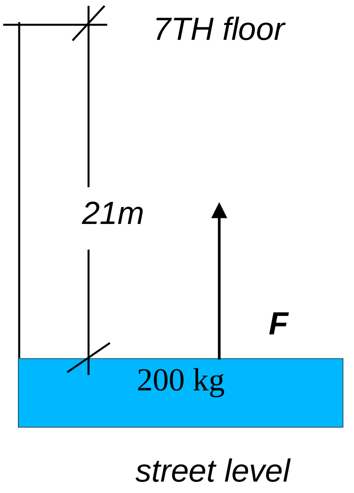
just over a tonne

WORKED EXAMPLE 3

Question: A bundle of steel conduit has a mass of 200kg is lifted to the seventh floor from street level.

1) How much energy is used to do this?
2) What power is required if the task needs to be completed in two minutes?

We need to make an assumption of floor heights and take 3m between each floor in this instance, therefore the total lift from street to 7TH floor would be 3m x 7 = 21m



We need to calculate the force required to overcome the gravitational force holding the bundle to the ground.

Force = mass x g
Force = 200kg x 9.81
Force = 1962N

and work done or energy used;

E = Force x Distance
= 1962N x 21m
= 41,202 Nm

*and as 1Nm = 1Joule then Energy used = 41,202 J **

To Calculate the power requirements needed to accomplish the task in two minutes we use the formula ;

Work = power x time

transposed to $\text{power} = \dfrac{\text{work done}}{\text{time}}$

$\text{power (watts)} = \dfrac{41{,}202 \text{ (watt seconds)*}}{60 \times 2 \text{ (seconds)}}$

power required = 343 watts

Note 1ws = 1Nm = 1J*

WORKED EXAMPLE 4

Question: Calculate the power an electric motor would need to deliver to run at 1400rpm when connected to an output of 50Nm load torque.

This problem employs the formula;

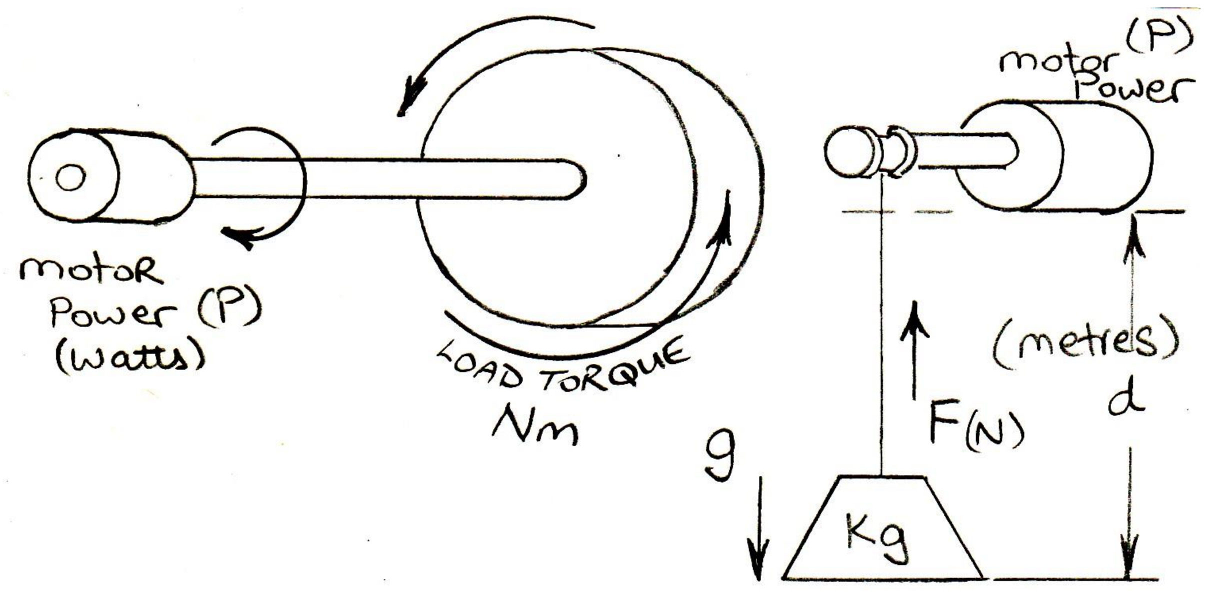
$$P = \frac{2\pi NT}{60}$$

$$\text{Power} = \frac{2\pi \text{ motor revolutions per minute} \times \text{load torque}}{60}$$

$$P = \frac{2\pi \times 1400 \times 50}{60}$$

$$P = 7330.4 \text{ watts or } 7.3 \text{ kW}$$

Notes: More power will be required to move the rotational load faster,
and
More power will be required to rotate a greater load.



We can liken the lifting of a mass a vertical distance with rotating a load a distance from a shaft centre.
To perform each task faster we would need to use a more powerful motor.

WORKED EXAMPLE 5

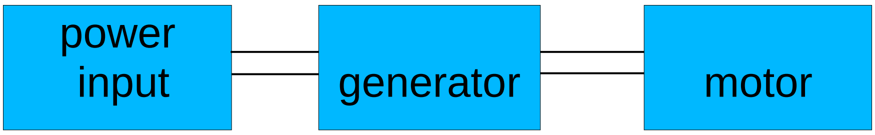
Question: An electric motor produces 20kW and is 80% efficient.
The generator that supplies this motor is 72% efficient.
What input power is required of the generator.

Looking at this situation with a sketch helps.

Electrical power **Mechanical**

Power

P = V x I $P = \frac{2\pi NT}{60}$



20kW output

72% eff *80% eff*

Note: "produces" means output.

The output of the motor is 20kW. The motor would need to be supplied this power plus the 20% of input power lost to the 80% efficiency rating. (80% + 20% = 100%)

ie: motor input $= 20kW \times \frac{100}{80} = 25kW$ *= generator output*

The 25kW of motor input power is supplied by the generator. It will need to produce this as its output. The generator would need an additional 28% of input power to compensate for its efficiency rating.

ie: $25kW \times \frac{100}{72} = 34.72kW$ *= generator input power*

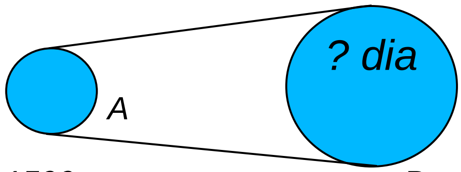
WORKED EXAMPLE 6

Question: Pulley A rotates at 1500 rpm with a diameter of 450mm. What is the diameter of pulley B if it is to rotate at 1200 rpm?

Answer: draw a sketch and add information to it to visualise what is happening.

Using the formula:

$$\frac{D1}{D2} = \frac{N2}{N1}$$



$$\frac{450mm}{D2} = \frac{1200\ rpm}{1500\ rpm}$$

and transposing for D2

$$D2 = \frac{450\ mm \times 1500\ rpm}{1200\ rpm}$$

$$\underline{D2 = 562.5\ mm}$$

Question: If we now measure the torque at pulley B and find it to be 100Nm, what is the torque at pulley A ?

Answer:

Again we use the formula $\frac{T1}{T2} = \frac{D1}{D2} = \frac{N2}{N1}$ *and choose the part of the relationship we need to solve for T1*

$$\frac{T1}{T2} = \frac{D1}{D2}$$

and transposing $T1 = \frac{T2 \times D1}{D2}$

$$T1 = \frac{100Nm \times 450mm}{562.5mm}$$

torque at pulley A = 80Nm