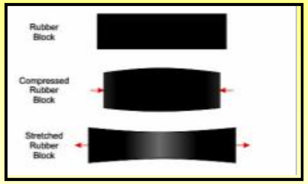
- A force acting on an object may cause a **change in shape of the object**.
- A force applied to an **elastic** object, such as **a spring**, will result in the object **stretching** and **storing elastic potential energy**.
- For an object that is able to recover its original shape, **elastic potential energy is stored** in the object **when work is done on the object to change its shape**.
- The extension of an elastic object is directly proportional to the force applied, provided that the limit of proportionality is not exceeded :

F is the **force** in **newton (N).**
k is the **spring constant** in **newton per metre (N/m).**
e is the **extension** in **metre (m).**

$$F = k \times e$$

FORCE MAY CHANGE THE SHAPE OF AN OBJECT

Squeezing a tennis ball will change its shape and when an elastic band is pulled, it will inevitably stretch or extend. The amount by which an object changes its shape when a pair of forces is applied depends on the rigidity of the object and the size of the applied force.



If the applied forces are **compressive**, the object may be squashed or compressed and if the applied forces are **tensile**, the object may be stretched or extended.

Springs and rubber bands are examples of **elastic** objects.

As we know from our everyday experience, when a force is applied to a spring, it stretches or extends. The bigger the applied force, the greater is the amount by which the spring extends.

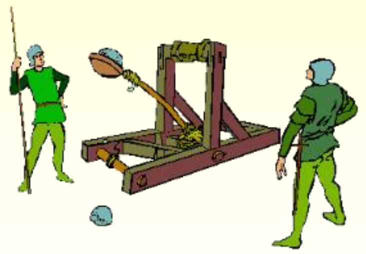
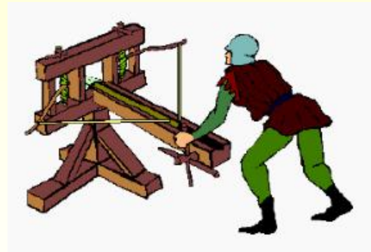
The **work done** against the spring's resistive force is then stored as **elastic potential energy** in the spring.

There are many examples in everyday life in which use is made of the **potential energy stored in a stretched elastic object.**

- The springs attached to the canvas of a trampoline are stretched as a person jumps down on the canvas and the **elastic potential energy** stored in the springs is then transferred to **kinetic energy** of the person, who is then propelled upwards into the air.

- A bow and arrow works on the same principle. **Elastic potential energy** is stored in the bowstring and when this is released, the stored energy is transferred to **kinetic energy** of the arrow.

- The medieval catapult and ballista shown below work in the same way.

Try to think of as many examples as possible, in which the potential energy stored in a stretched or compressed elastic object is used in some way.

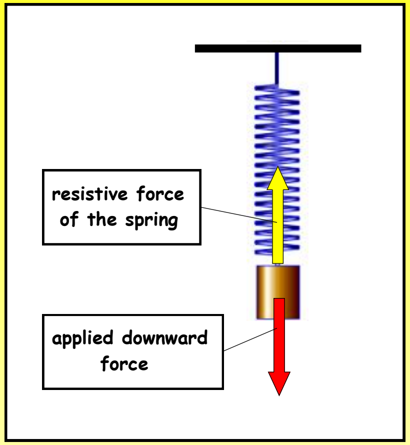
STORED ELASTIC POTENTIAL ENERGY

Consider a spring which is suspended vertically and has a mass attached to its lower end.

When the mass is pulled down by an applied force, the spring extends.

The **work done** against the spring's resistive force is then stored as **elastic potential energy** in the spring.

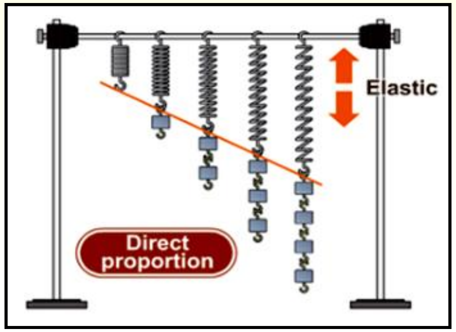
When the mass is released by removing the applied force, the **elastic potential energy** stored in the spring is transferred to **kinetic energy** of the mass and spring, which then shoot upwards.

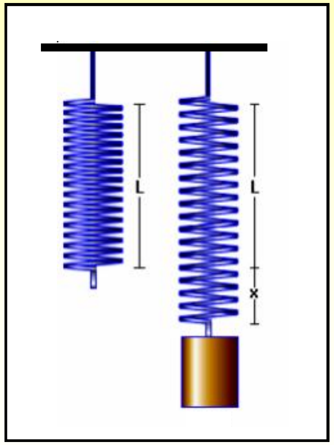


HOOKE'S LAW

When a spring of original length **(L)** is loaded, it will stretch by a certain amount **(x),** which is called the **extension.**

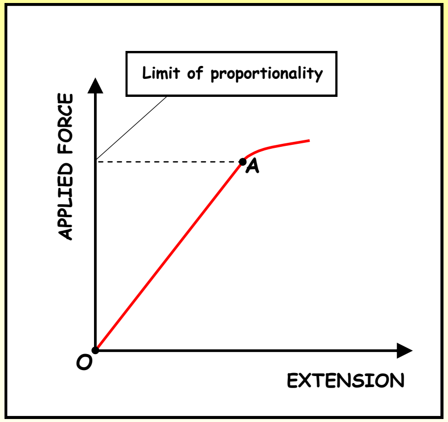
If we increase the load continuously, the extension (x) increases in direct proportion (i.e. if the load is doubled, x will also be doubled and if the load is trebled, x will be trebled)





- The **extension is directly proportional to the applied force** until a certain value of force is reached (called the **limit of proportionality**), beyond which the extension is no longer proportional to the applied force.
- For applied force values **up to the limit of proportionality**, the **spring will return to its original length once the force is removed**.
- If the applied force value **exceeds the limit of proportionality**, the **spring does not return to its original length when the force is removed** (i.e. it is left permanently deformed).

If we plot a graph of **applied force** against **extension** for a spring, it can be seen that the extension of the spring is **directly proportional** to the applied force up to a certain value of this applied force, which is called the **limit of proportionality**. Thus, section **OA** of the graph is a straight line.



Up to this value of applied force, if the force is removed, the extension would be zero (i.e. the spring would return to its original length).

When the applied force is increased beyond the limit of proportionality, the extension is **no longer proportional** to the applied force (shown by the fact that beyond **A** the graph is no longer a straight line).

When the force is removed, the extension does not return to zero and the spring is now permanently extended.

Robert Hooke invented, amongst other things, the iris diaphragm in cameras, the universal joint used in motor vehicles, the balance wheel in a watch and the first reflecting telescope. He originated the word 'cell' in biology and he worked as an architect, scientist and engineer, but he is known mostly for his work on the elastic behaviour of solids which is embodied in **Hooke's law**.

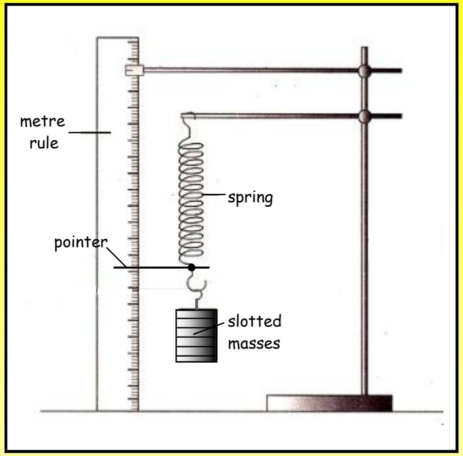
The **extension** of an elastic object is **directly proportional** to the **force applied**, provided that the **limit of proportionality is not exceeded** :

This is expressed mathematically by the equation :

$$F = k \times e$$

F is the **force** in **newton (N)**.
k is the **spring constant** in **newton per metre (N/m)**.
e is the **extension** in **metre (m)**.

PRACTICAL WORK : EXPERIMENTAL VERIFICATION OF HOOKE'S LAW



- The apparatus is set up as shown in the diagram and the pointer reading on the metre rule is noted with the spring completely unloaded.
- The spring is then loaded with a **50 g** mass (≈ **0.5 N** force) and the new pointer reading is recorded. The **extension** is then the difference between this new reading and the original, unloaded reading.
- The mass loading the spring is then increased to **100, 150, 200, 250** and **300 g** and the new pointer reading, as well as the calculated extension is recorded in each case.

mass/g	force/N	original reading/cm	new reading/cm	extension/cm
0	0.0			
50	0.5			
100	1.0			
150	1.5			
200	2.0			
250	2.5			
300	3.0			

- Use your results to plot a graph of **force/N** (along the vertical axis) against **extension/cm** (along the horizontal axis).

SOME QUESTIONS

- What sort of graph did you obtain?

- Does your graph **verify or contradict Hooke's law?** Explain why.

- Given that the mathematical expression of **Hooke's law** is : $F = k \times e$

Where : **F** is the **force** in **newton (N).**
k is the **spring constant** in **newton per centimetre (N/cm).**
e is the **extension** in **centimetre (cm).**

Use your graph to calculate the **spring constant (k).**

- PRACTICE QUESTIONS

1 **(a)** A stretched spring stores **elastic potential energy**. Explain, in terms of **work done**, how this happens.

(b) Name **two** everyday examples in which stored elastic potential energy is made use of. In each case state the **energy transfer** which occurs.

2 **(a)** State **Hooker's law**.

(b) Write down an **equation** which expresses **Hooke's law** mathematically, stating what each term in the equation represents.

3 **(a)** Sketch a fully labelled graph of **applied force** against **extension** for a spring which is loaded beyond its **limit of proportionality**.

(b) Explain what is meant by the spring's **'limit of proportionality'**.

4 A spring has a spring constant of **150 N/m.** Calculate :

(a) The **force** which must be applied to extend the spring by **5 cm**.

(b) The amount by which the spring will **be extended** when a force of **6.5 N** is applied to it.

(c) The **mass in grams** which must be hung from the spring in order to extend it by **10 cm.**