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37 Springs and Elastic Deformation

extension = (length of a spring or material) – (its unstretched length)

For a spring or any material below its limit of proportionality, the force stretching (or compressing) the material is **proportional** to its extension (or compression). Twice the force causes twice the extension. This is Hooke's Law.

When the force is removed, it goes back to its **original length**. This is called **elastic deformation**.

The spring constant k measures the force needed to stretch it by 1 cm or 1 m. The unit of the spring constant is N/cm or N/m.

Formula:

$$\text{force (N)} = \text{spring constant (N/m)} \times \text{extension (m)} \qquad F = kx$$

For extension, two symbols are commonly used, e and x .

Example 1 – A spring is 5.0 cm long when unstretched. With a 6.0 N force stretching it, it becomes 13 cm long. What is the spring constant?

$$\text{extension} = 13.0 \text{ cm} - 5.0 \text{ cm} = 8.0 \text{ cm}.$$

$$\begin{aligned} \text{spring constant} &= \text{force/extension} = 6.0 \text{ N}/8.0 \text{ cm} = 0.75 \text{ N/cm} \\ &\text{or } 6.0 \text{ N}/0.080 \text{ m} = 75 \text{ N/m} \end{aligned}$$

Example 2 – What will the length of this spring be when it is stretched with a 9.0 N force?

$$\begin{aligned} \text{extension} &= \text{force/spring constant} = 9.0 \text{ N}/(0.75 \text{ N/cm}) = 12 \text{ cm} \\ \text{length} &= 5.0 \text{ cm} + 12 \text{ cm} = 17 \text{ cm}. \end{aligned}$$

37.1 A spring takes a force of 5.0 N to extend it by 2.0 cm.

(a) What is the spring constant in N/m?

- (b) What force is needed to extend it by 10 cm?
- (c) What force is needed to extend it by 12 cm?
- (d) What force is needed to extend it by 5.0 mm?
- (e) What is the extension when the force is 45 N?
- (f) What is the extension when the force is 7.0 N?

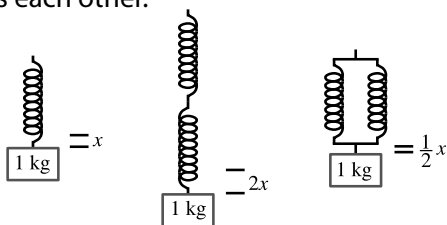
37.2 A spring is 6.0 cm long when it is not stretched, and 10 cm long when a 7.0 N force is applied.

- (a) What is the spring constant in N/m?
- (b) How long will it be with a 21 N force?
- (c) How long will it be with a 5.0 N force?
- (d) What force is needed to make it 20 cm long?

37.3 A company is making newton meters using 150 N/m springs.

- (a) How far from the 0.0 N mark will the 10 N mark need to be?
- (b) How far apart will the 4.0 N and 9.0 N marks be?

When two springs support a weight in series (one hanging off the other), they each carry the full weight of the load. When two identical springs support a weight in parallel, they share the weight of the load, but have the same extension as each other.



37.4 Two identical springs each have a spring constant of 200 N/m. A mass of 9.7 kg is hung from one spring, which is supported by the other. The top spring is supported by a strong beam.

- (a) What is the total extension of the springs?
- (b) The two springs are now set up in parallel to share the load.

What is the extension of each spring when the mass is supported?

Potential energy stored in a stretched spring

work done when stretching a spring = force \times distance

However, the force changes as you stretch the spring. To start with, very little force is needed to stretch it. At the end, the force is $F = kx$ where x is the final extension. The average force is $\frac{1}{2}kx$.

work done in stretching a spring = average force \times distance

$$= \frac{1}{2}kx \times x = \frac{1}{2}kx^2$$

elastic potential energy (J) = $\frac{1}{2} \times$ spring constant \times extension²

$$E = \frac{1}{2}kx^2$$

Example 3 – Calculate the elastic potential energy stored when a 1 000 N/m spring is stretched by 3.0 cm from its natural length.

With energy calculations, you should always use distances in metres.

$$\text{Energy} = \frac{1}{2}kx^2 = \frac{1}{2} \times 1\,000 \text{ N/m} \times (0.030 \text{ m})^2 = 0.45 \text{ J}$$

- 37.5** Calculate the elastic potential energy stored when a 1 000 N/m spring is stretched by 6.0 cm from its natural length.
- 37.6** Calculate the elastic potential energy stored when a 1 000 N/m spring is stretched by a 20 N force. [Hint: first work out the extension.]
- 37.7** Calculate the extension of a 500 N/m spring when storing 3.0 J.
- 37.8** [Harder] Calculate the elastic potential energy when a 40 N force stretches a spring by 0.50 cm.
- 37.9** How much strain energy is
- (a) stored in a 40 kN/m spring when it is stretched by 3.0 cm?
 - (b) released on now relaxing to a stretch of 1.5 cm?