Engineering **enables**

Royal Academy of Engineering

THIS IS ENGINEERING

Key words and concepts

Strength, density, force, potential energy, kinetic energy, stiffness, elasticity, Hooke's law, prosthetics, newtons, strength to weight ratio, carbon reinforced polymer, kilogram, carbon fibre, composite

Introduction

When he was 21 years old, Van Phillips had his left leg amputated below the knee as the result of an accident.

He was given a prosthetic leg, but was frustrated that it didn't work like his other leg. He called it a 'dumb leg' because it was heavy and it wouldn't allow him to run and jump like he had done before his accident.

Van decided to design a prosthetic leg that would enable him to bounce, jump and run like he had been able to before his accident.

After years of designing, making, testing and breaking lots of prototypes, Van developed a prosthetic leg that enabled him to start running again.

Time to observe

With a partner, observe how we move our bodies and use our muscles to jump as high as we can from a standing position.

Which parts of our bodies do we move to jump as high as we can from a standing position?

Use drawings to show the stages involved in jumping from a standing position.

- Now observe how you and your partner move your bodies and use your muscles when you bounce up and down on the spot
- Is the movement different to when we try to jump as high as we can from a standing position?

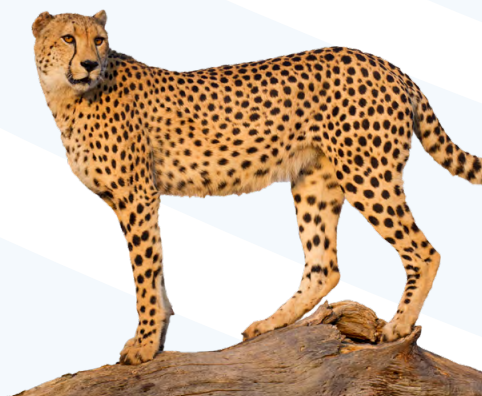
As you will have observed, jumping and bouncing on the spot involves bending our knees and pushing against the ground with our feet and toes.

When we jump or bounce, we behave a bit like a spring that has been compressed (squashed down) and then released.

Elastic potential energy

When we compress (or squash) a spring we store energy. This energy is released when we remove the force that is compressing the spring. The energy stored in the spring is called elastic potential energy.

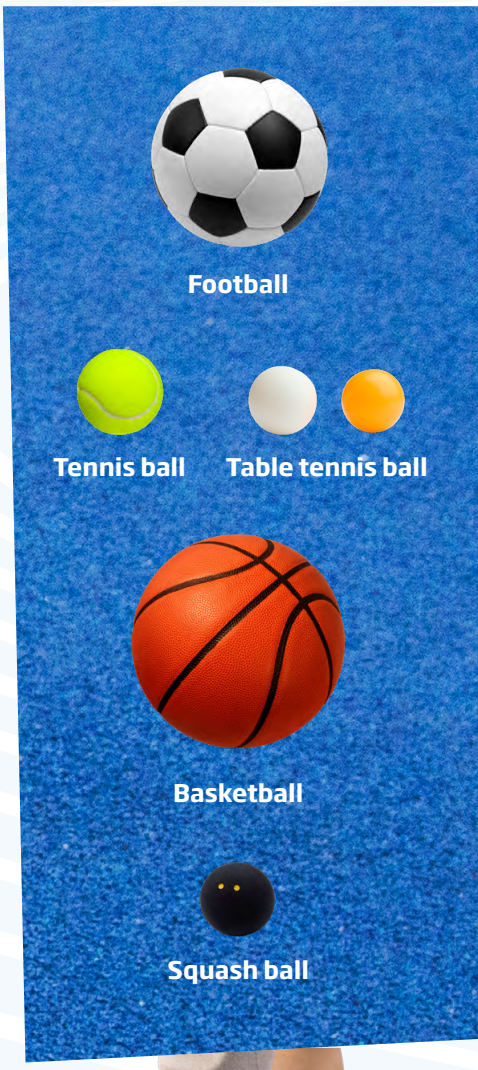
What is the energy, stored in a compressed spring, converted into when the compression force is removed?



Time to investigate

Get hold of a number of different types of balls (some examples are given, right).

- Drop each of the balls from the same height
- How will you identify the ball with the most elastic potential energy?
- Discuss why the balls in your test might have different levels of elastic potential energy



Stretch and challenge - Hooke's law

Hooke's law states that the amount an elastic material changes when it is compressed (squashed) or extended (stretched) is directly proportional to the force applied to it.

The equation for Hooke's law is

$$F = -k \times e$$

where **F** = force (measured in newtons, N), **k** = the 'spring constant' or the stiffness of the specific material (measured in newtons per metre, N/m) and **e** = the extension (measured in metres, m).

Hooke's law can also be used to calculate the potential energy in an elastic material or form, such as a spring.

$$U = \frac{1}{2} ke^2$$

where **U** = potential energy (measured in joules, J), **k** = the 'spring constant' (measured in newtons per metre, N/m) and **e** = the extension or compression (measured in metres, m).

Calculate the potential energy in the spring described in the table below.

Spring material	Spring constant (N/m)	Extension (m)
Mild steel	100	0.05

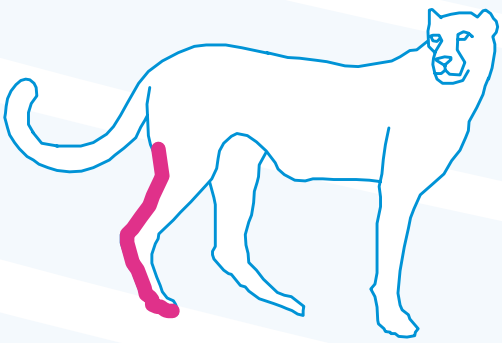
Problem solving

To solve the problem Van had identified, he realised that his new prosthetic leg needed to:

- be lighter than existing prosthetic legs
- resist the forces exerted on it by the wearer
- utilise elastic potential energy like a fully functioning leg

Inspired by nature

Van turned to nature for inspiration. The skeleton of the fastest land mammal, the cheetah, helped him to identify the shape of the prosthetic.



Aircraft technology

Van Phillips considered a number of materials from which to make his new prosthetic leg. Some of these materials are included in the table below, which shows the strength and density of each material. Remember, Van was looking for a very light and very strong material – something with a good strength to weight ratio, which is also called specific strength.

Van made his decision about the best material to use to make his new prosthetic leg after a discussion with an aerospace engineer.

Why do you think the aerospace engineer was a good person to advise Van about which material to use?

Time to calculate

You can discover the specific strength of a material by dividing the figure for its strength by the value given for its density.

Specific strength = strength / density

Material	Ultimate strength (MN/m^2)	Density (kg/m^3)	Specific strength (MNm/kg)
Aluminium alloy (6061-T6)	300	2700	
Carbon fibre reinforced polymer (CFRP)	1600	1750	
Glass fibre reinforced plastic (GFRP)	1500	2570	
Nylon (type 66)	75	1150	
Rubber	15	1200	
Stainless steel	860	8190	
Titanium	1040	4500	
Pine	40	510	

- Use the data in the table to calculate the specific strength of the materials listed
- Add the answers to a copy of the table
- Draw a chart that compares the specific strength of the materials in the table
- Which material do you think Van Phillips chose to make his new prosthetic leg from?
- Give a reason for your suggestion

Extension

Learn more about Van Phillips and his prosthetic leg design from the Smithsonian Institute via the following links:

Van Phillips online article
http://invention.smithsonian.org/centerpieces/ilives/van_phillips/van_phillips.html

Van Phillips video
http://invention.smithsonian.org/centerpieces/inventingourselves/pop-ups/van_video.htm

Learn more about the mechanical properties of materials from Cambridge University at:
www-materials.eng.cam.ac.uk/mpsite/materials.html

Investigate the companies that make prosthetics for athletics
www.ossur.co.uk
www.ottobock.co.uk

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