A LEVEL DESIGN ENGINEERING

6.5 FORCES

Learning objectives

- How do forces interact with structures?
- What are static and dynamic forces?
- What are stress, strain and elasticity?
- Which calculations are used in structural engineering?

Key words:

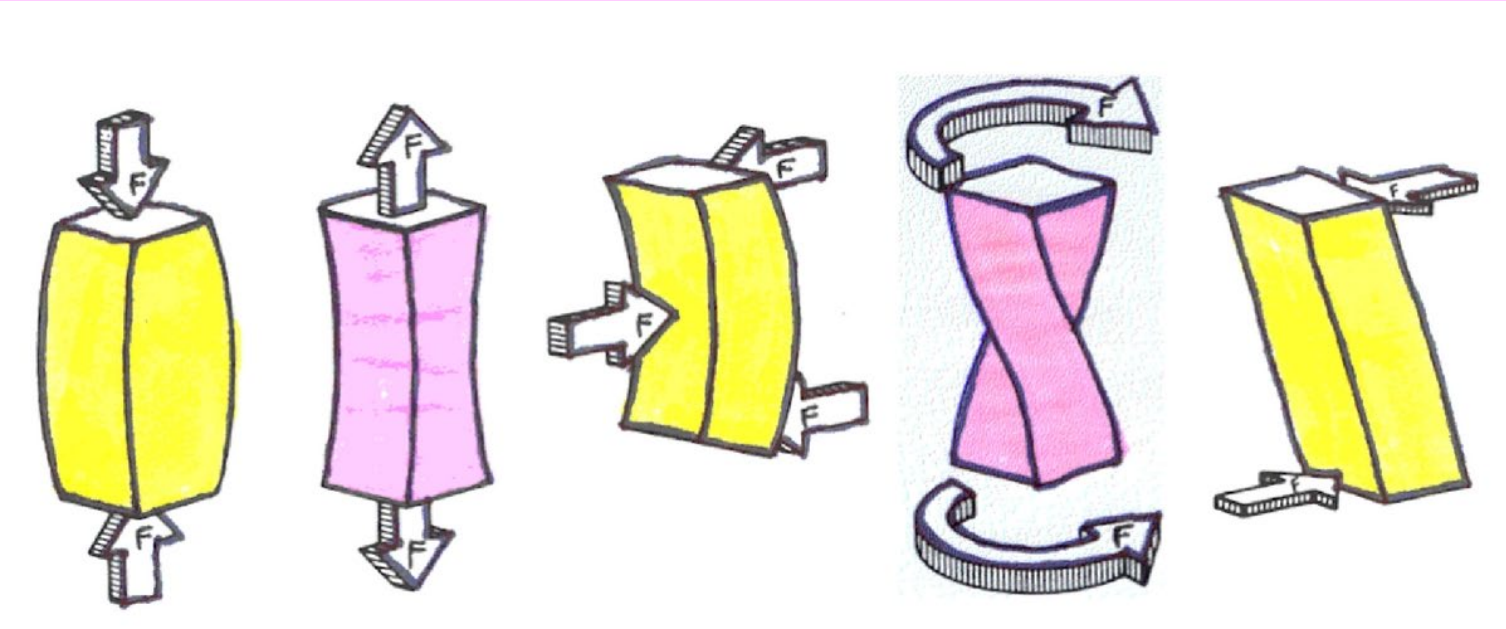
Tension, compression, torsion, bending, stress, strain, elasticity, mass, weight, Young's modulus

Learning objectives:

- Which terms are used in circuit design and construction?
- What are the types of electronic component?

Explanation

Which **forces** act on materials?



Compression **Tension** **Bending** **Torsion** **Shearing**

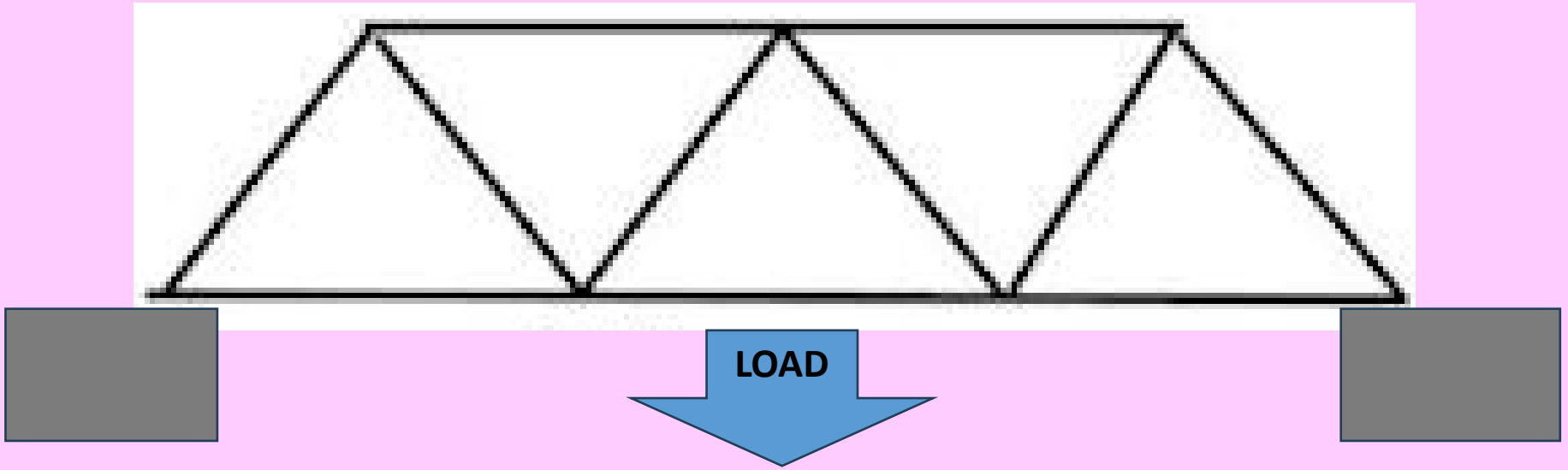
Learning objectives:

- ❑ Which terms are used in circuit design and construction?
- ❑ What are the types of electronic component?

Explanation

What is the difference between a **strut** and a **tie**?

Which of these beams would be in **tension**?
Which would be in **compression**?



Learning objectives:

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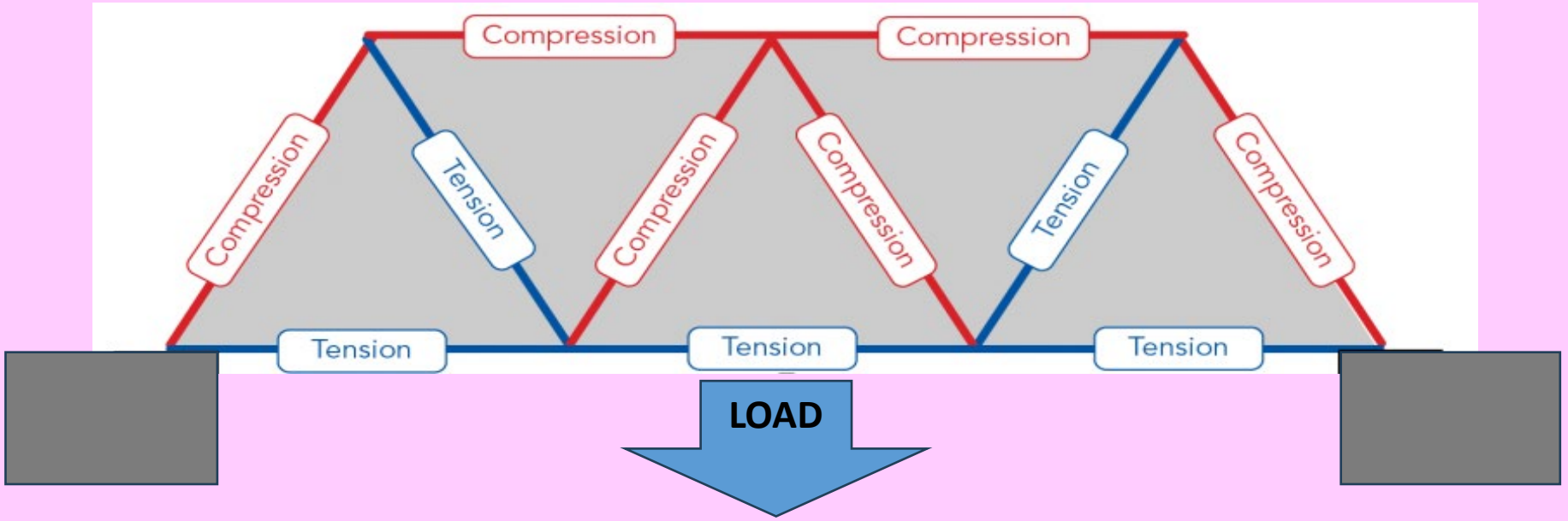

Learning objectives:

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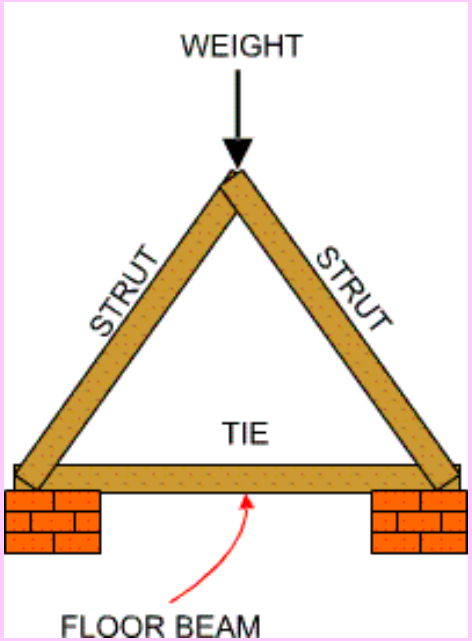
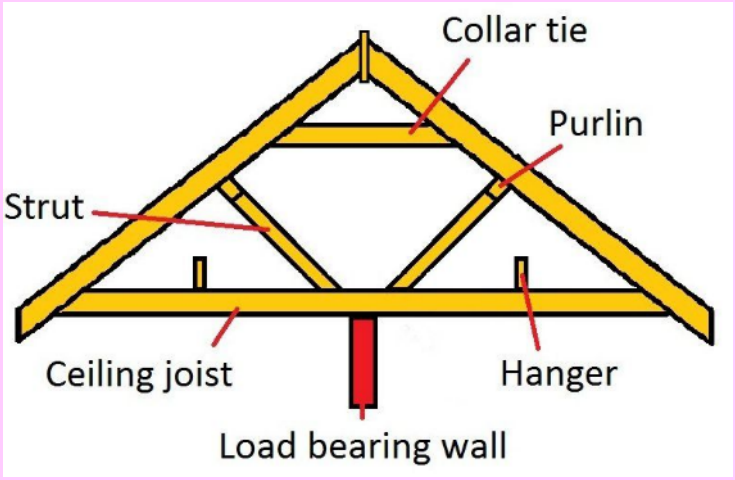
Explanation

What is the difference between a **strut** and a **tie**?

A **strut** resists compression



A **tie** resists tension



Learning objectives:

- ❑ Which terms are used in circuit design and construction?
- ❑ What are the types of electronic component?

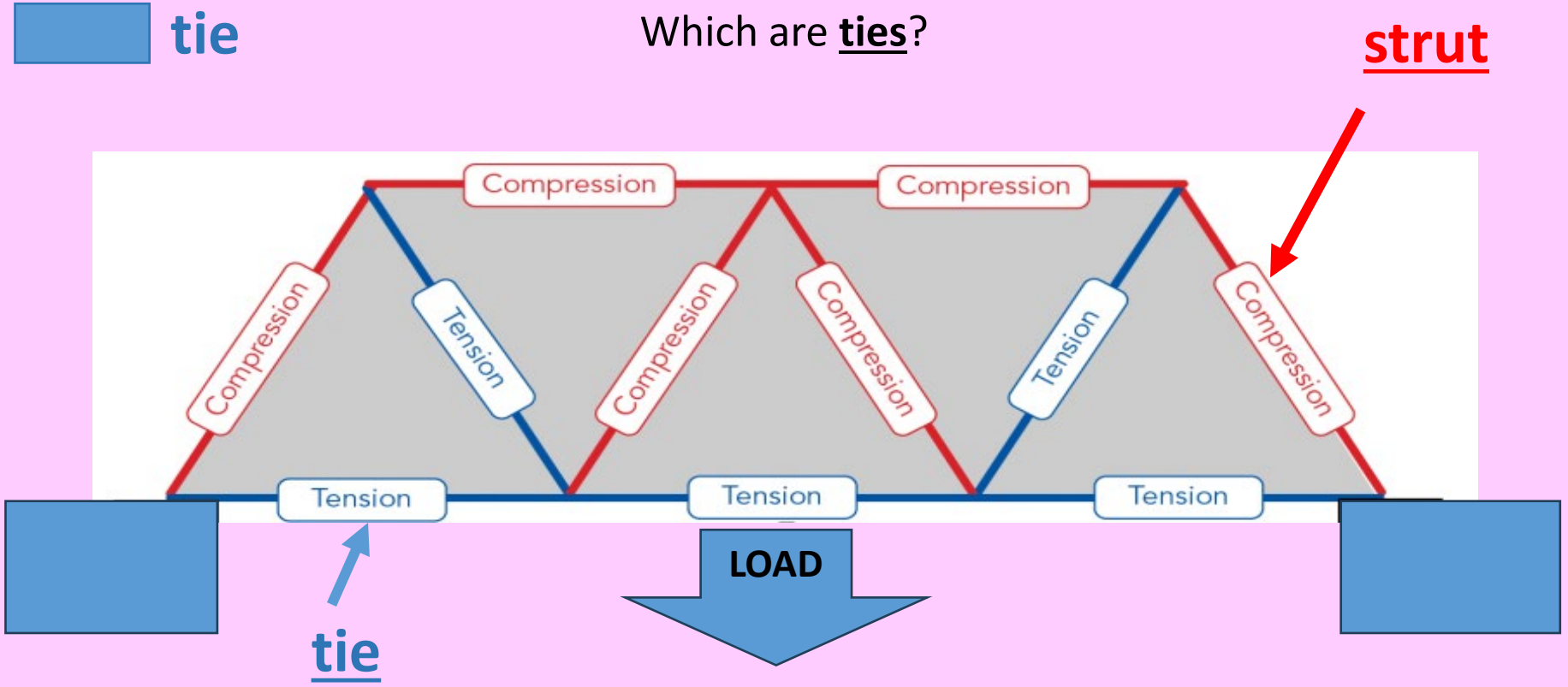
Explanation

How do forces interact with structures?

strut

tie

Which of these beams are **struts**?
Which are **ties**?



Learning objectives:

- ❑ Which terms are used in circuit design and construction?
- ❑ What are the types of electronic component?

Explanation

What is the difference between a **static** and **dynamic** force?

Static force is always present

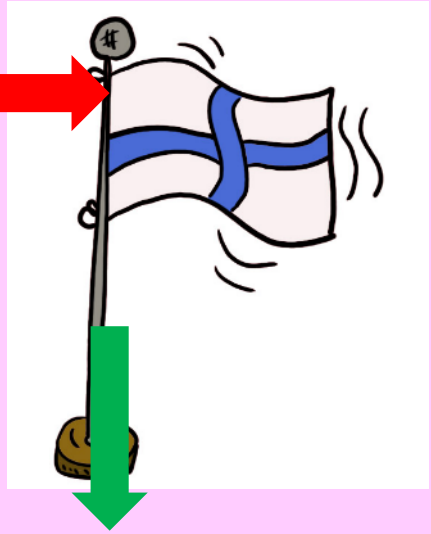
Dynamic forces may move

Can you identify the **static** and **dynamic** forces on these two situations?

Dynamic: force of the user leaning back on the chair

Static: The weight of the chair

Dynamic: force of the wind



Static: The weight of flag pole

Learning objectives:

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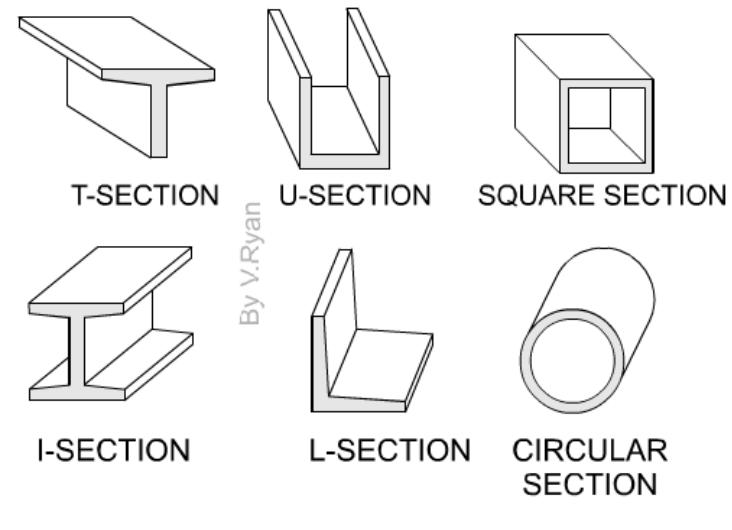
Explanation

How can we increase **rigidity** in a structure?

Using cross sections, struts and ties effectively to save weight



Learning objectives:

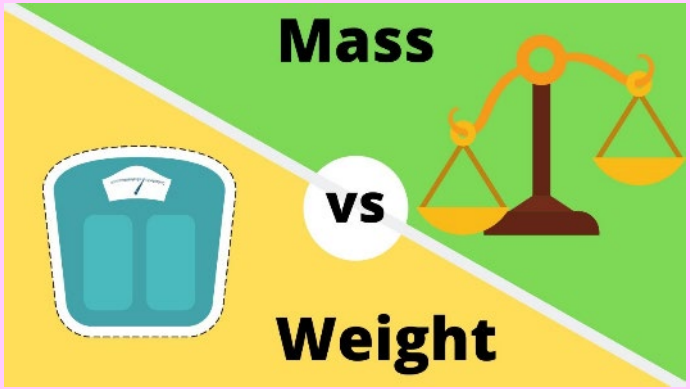
- ❑ Which terms are used in circuit design and construction?
- ❑ What are the types of electronic component?

Explanation

What do we mean by **force**, **mass** and **weight**?

What is the definition of the **mass** of an object?

The amount of material an object contains (Kg)



What is the definition of the **weight** of an object?

The force of gravity pulling down on an object (N)

Learning objectives:

- ❑ Which terms are used in circuit design and construction?
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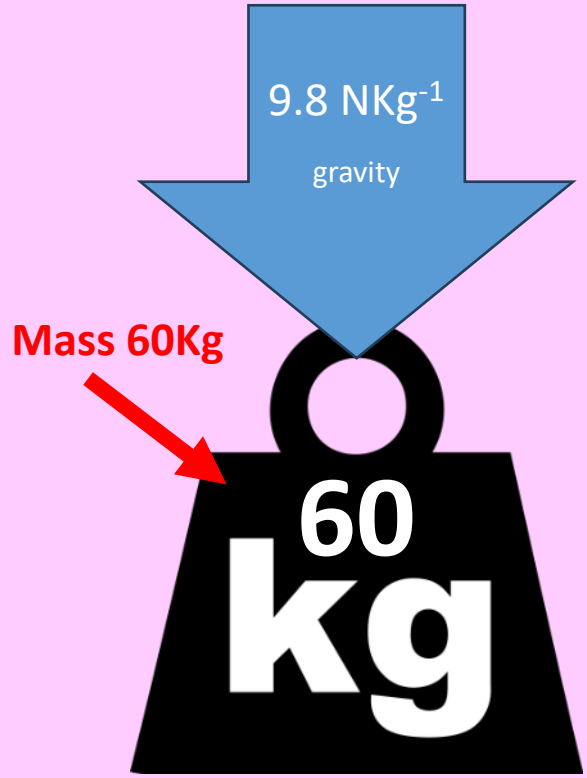
Explanation

What do we mean by **force**, **mass** and **weight**?

How do we **calculate weight**?

Weight (N) = mass (Kg) x gravitational field strength

The force of gravity on earth = 9.8 Nkg^{-1}



If an object has a mass of **60Kg** what would its weight be on earth?

Weight = 60 x 9.8

Weight = 588 N

Learning objectives:

- ❑ Which terms are used in circuit design and construction?
- ❑ What are the types of electronic component?

Explanation

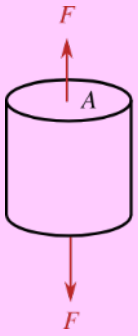
How can we calculate a components **ability to carry load**?

What do we mean by the terms **stress** and **strain**

Stress is the force per unit of area

Strain is the amount a material deforms through stress

How can we **calculate stress and strain**?

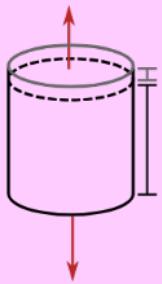


$$stress(Pa) = \frac{force\ (N)}{cross\ sectional\ area\ (m^2)}$$

1 Pascal (Pa) = $1Nm^{-2}$

$$strain = \frac{extension}{original\ length}$$

Strain is a ratio and has no units!



Learning objectives:

- ❑ Which terms are used in circuit design and construction?
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Explanation

How are stress and strain linked?

Young's modulus

The resistance of a material to elastic deformation under load

How do we calculate Young's modulus

$$\text{Young's modulus (Pa)} = \frac{stress}{strain}$$

Learning objectives:

- ❑ Which terms are used in circuit design and construction?
- ❑ What are the types of electronic component?

Explanation

What is the Young's modulus of different materials?

e.g. Young's modulus of steel is 200 Gpa (Giga Pascals)

Prefixes	Value	Standard form	Symbol
Tera	1 000 000 000 000	10^{12}	T
Giga	1 000 000 000	10^{9}	G
Mega	1 000 000	10^{6}	M
Kilo	1 000	10^{3}	k
Deci	0.1	10^{-1}	d
Centi	0.01	10^{-2}	c
Milli	0.001	10^{-3}	m
Micro	0.000 001	10^{-6}	μ
Nano	0.000 000 001	10^{-9}	n
Pico	0.000 000 000 001	10^{-12}	p

200 GPa = 200 x 10^9 Pa = 200,000,000,000 Pa

Material	Youngs Modulus (GPa)
Rubber (small strain)	0.01-0.1
PTFE (Teflon)	0.5
Polyethylene (low density)	0.2
Polypropylene	1.5-2
Polystyrene	3-3.5
Nylon	2-4
Fiber board (medium density)	3.654
Wood (along grain)	8.963-11
High-strength Concrete (under compression)	30
Glass fiber reinforced plastic (70/30 by weight fibre/matrix, along grain)	40-45
Magnesium (Mg)	45
Aluminium (Al)	69
Abrasive Ceramics (vitrified/bonded)	20-90
Glass	50-90
Mother-of-Pearl (nacre, largely calcium carbonate)	70
Brass and Bronze	100-125
Titanium (Ti) and Titanium Alloys	105-120
Copper (Cu)	117
Carbon fiber reinforced plastic (50/50 fibre/matrix, unidirectional, along grain)	125-150
Steel	200
Beryllium (Be)	287
Tungsten (W)	400-410
Sapphire (Al_2O_3) along C-axis	435
Silicon Carbide (SiC)	450
Osmium (Os)	550
Tungsten Carbide (WC)	450-650
Single-Walled Carbon Nanotube	1,000+
Diamond (C)	1220

Learning objectives:

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Explanation

How can we use the **Young's modulus** to calculate the **extension** of a material

Polypropylene has a Young's modulus of **2 GPa**
A polypropylene bar of **0.01 m** radius and **1000mm** length has a force of **500N** applied how much would it extend?

Young's modulus = 2GPa = 2,000,000,000 Pa = 2×10^9 Pa

Radius = 0.01m

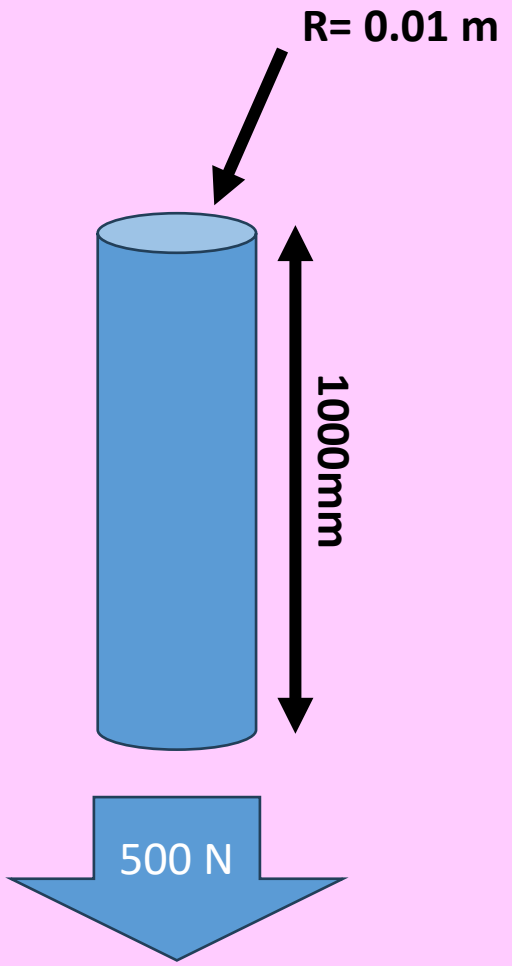
Force = 500N

Original length = 1000mm

$$\text{Stress (Pa)} = \frac{\text{force (N)}}{\text{cross sectional area (m}^2\text{)}}$$

$$\text{Strain} = \frac{\text{extension}}{\text{original length}}$$

$$\text{Youngs modulus (Pa)} = \frac{\text{stress}}{\text{strain}}$$



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Explanation

How can we use the **Young's modulus** to calculate the **extension** of a material

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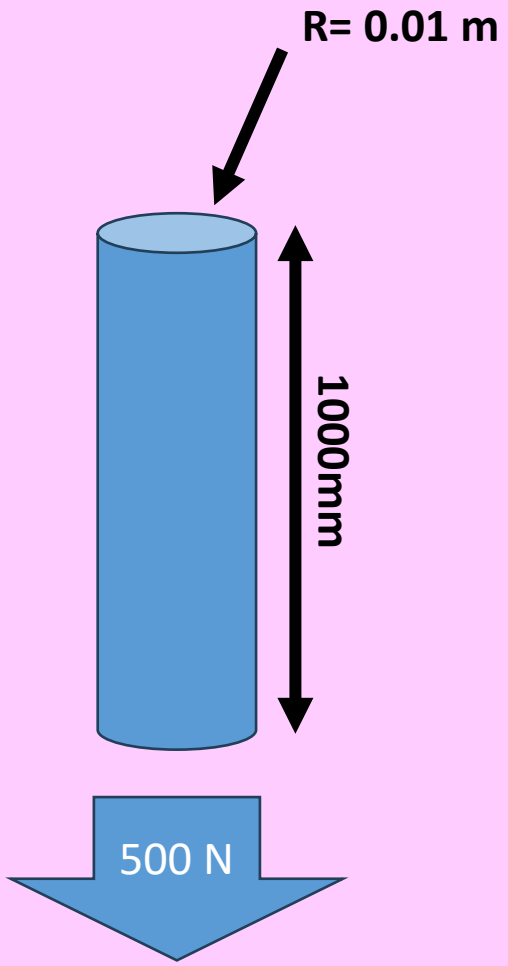
Radius = 0.01m

Force = 500N

Original length = 1000mm



Area= πr^2

Area= π 0.01^2

Area= $3.14 \times 10^{-4} m^2$

$$\text{Stress} = \frac{\text{force}}{\text{cross sectional area}}$$

$$\text{Stress} = \frac{500}{3.14 \times 10^{-4}}$$

Stress = 1591549.43 Pa

Learning objectives:

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Explanation

How can we use the **Young's modulus** to calculate the **extension** of a material

Young's modulus = 2GPa = 2,000,000,000 Pa = 2 x 10^9 Pa

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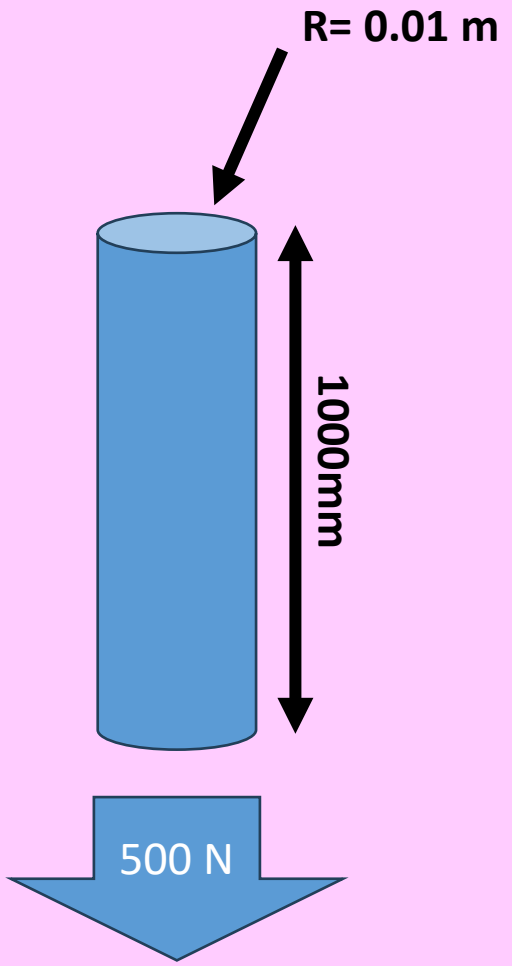

Stress = 1591549.43 Pa

$$\text{Youngs modulus (Pa)} = \frac{\text{stress}}{\text{strain}}$$

$$\text{Strain} = \frac{\text{stress}}{\text{Young's modulus}}$$

$$= \frac{1591549.43}{2 \times 10^9}$$

$$= 7.95 \times 10^{-4}$$

$$= 0.00079$$

Learning objectives:

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How can we use the **Young's modulus** to calculate the **extension** of a material

Young's modulus = 2GPa = 2,000,000,000 Pa = 2 x 10^9 Pa

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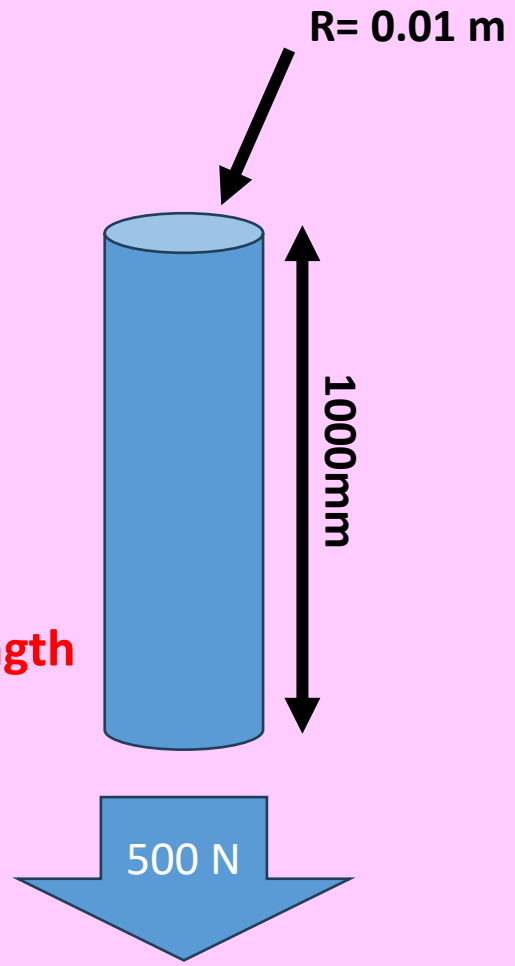

Stress = 1591549.43 Pa

Strain = 7.95x10^{-4}

$$\text{Strain} = \frac{\text{extension}}{\text{original length}}$$

Extension = strain x original length

= 7.95x10^{-4} x 1000

= 0.795 mm

Change in length from 1000mm to 1000.8mm

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How can we use the **Young's modulus** to calculate the **extension** of a material

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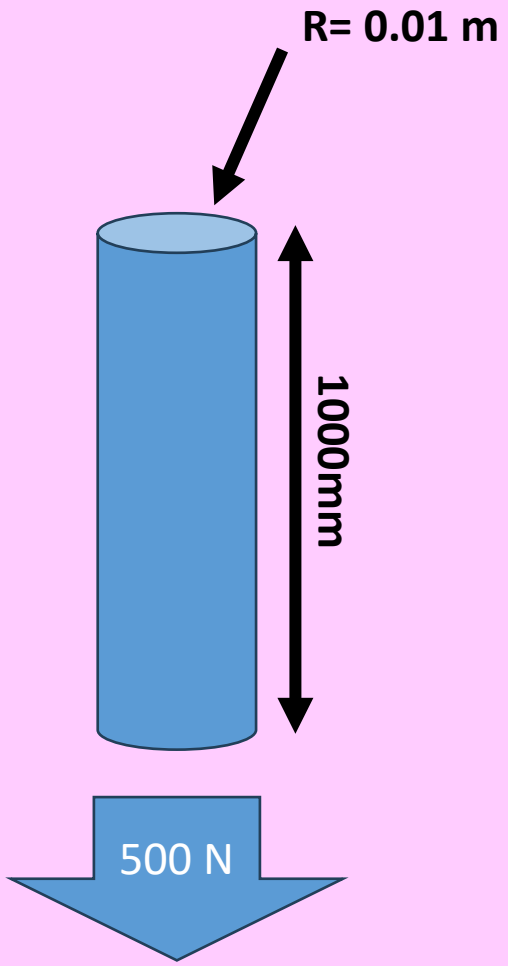

Area= π r^2

Area= π 0.01^2

Area= $0.0003m^2$

$$\text{Stress} = \frac{\text{force}}{\text{cross sectional area}}$$

$$\text{Stress} = \frac{500}{0.0003}$$

Stress = 1666666.66 Pa

Learning objectives:

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Explanation

How can we use the **Young's modulus** to calculate the **extension** of a material

Young's modulus = 2GPa = 2,000,000,000 Pa = 2 x 10^9 Pa

Radius = 0.01m

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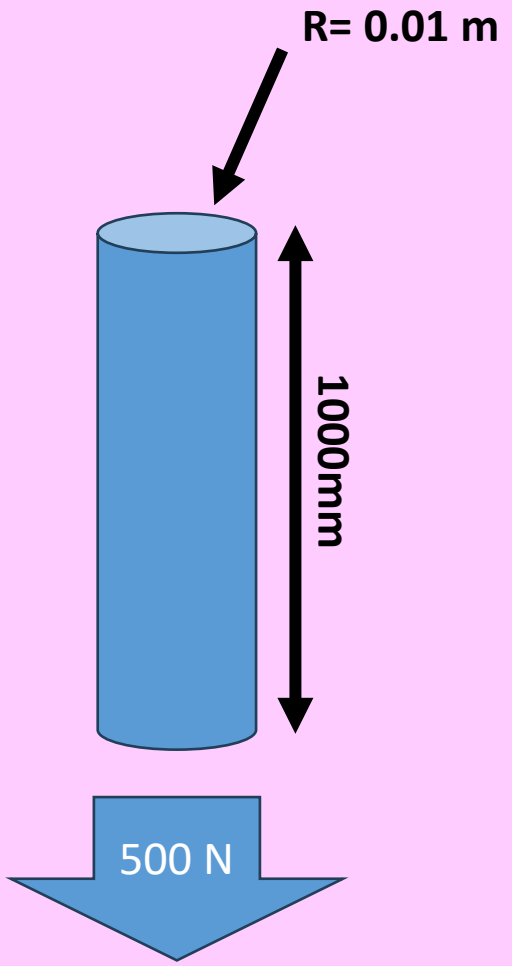
Original length = 1000mm



Stress = 1666666.66 Pa

$$\text{Youngs modulus (Pa)} = \frac{\text{stress}}{\text{strain}}$$

$$\text{Strain} = \frac{\text{stress}}{\text{Young's modulus}}$$

$$= \frac{1666666.66}{2 \times 10^9}$$

$$= 0.0008$$

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How can we use the **Young's modulus** to calculate the **extension** of a material

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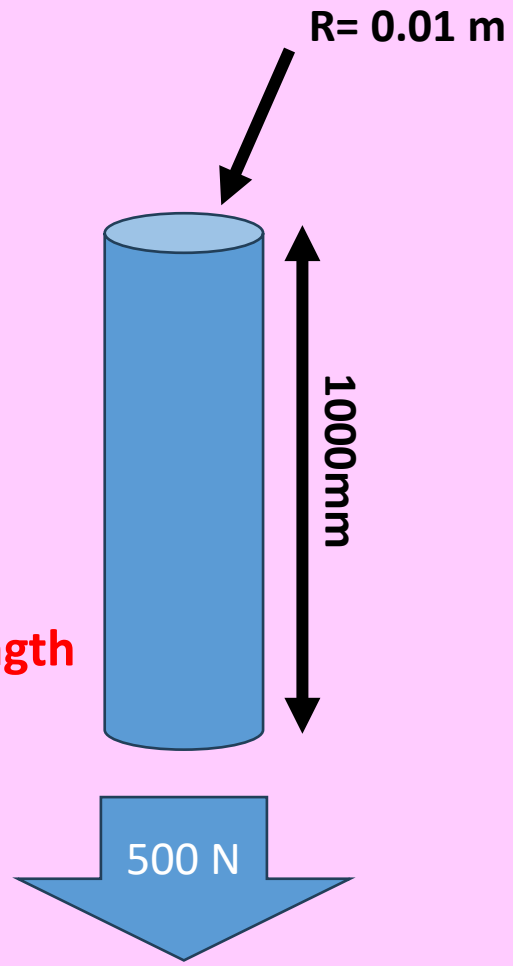

Stress = 1666666.66 Pa

Strain = 0.0008

$$\text{Strain} = \frac{\text{extension}}{\text{original length}}$$

Extension = strain x original length

= 0.0008 x 1000

= 0.8 mm

Change in length from 1000mm to 1000.8mm

Learning objectives:

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