This lesson is being recorded

King's InterHigh

LEADING ONLINE SCHOOL

Explore 1: Analogies for Electricity

Electricity – Fundamentals

Objectives

understand that electric current is the rate of flow of charged particles and be able to use the equation $I = \frac{\Delta Q}{\Delta t}$
understand how to use the equation $V = \frac{W}{Q}$
understand that resistance is defined by $R = \frac{V}{I}$ and that Ohm's law is a special case when $I \propto V$ for constant temperature
understand how the distribution of current in a circuit is a consequence of charge conservation
understand how the distribution of potential differences in a circuit is a consequence of energy conservation
be able to derive the equations for combining resistances in series and parallel using the principles of charge and energy conservation, and be able to use these equations

Starter

Playful Penguin Race 0.32 min

Watch the clip.

Explain how it could be a model for an electrical circuit.

Try and think of 4 elements.

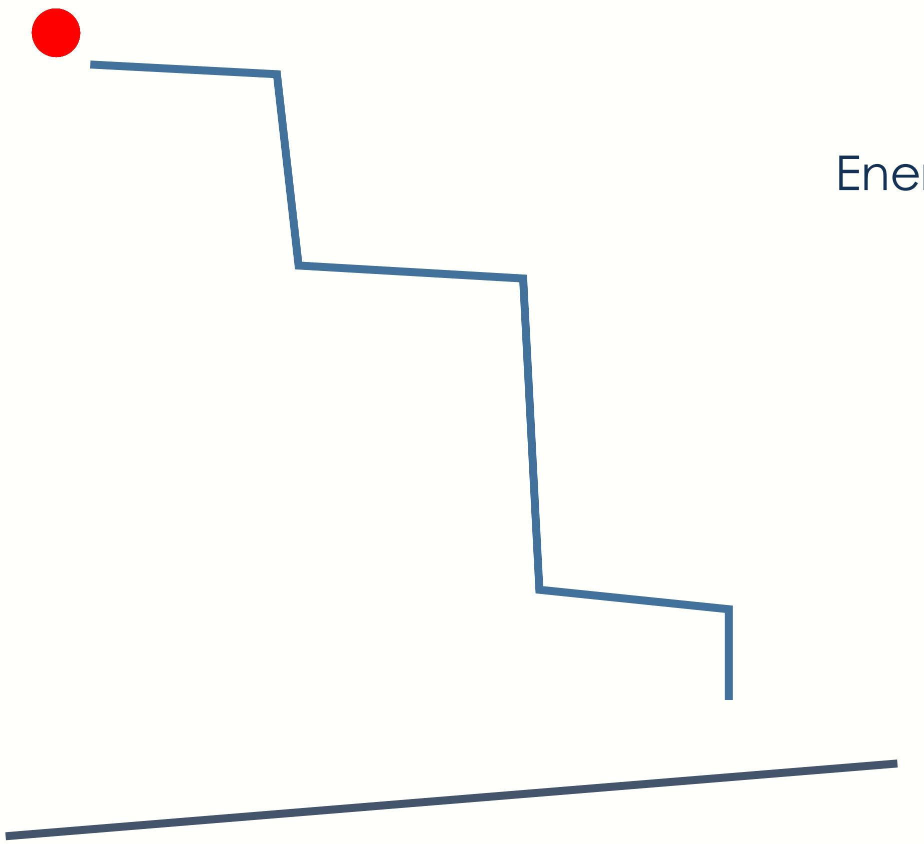
Stairs: Cell

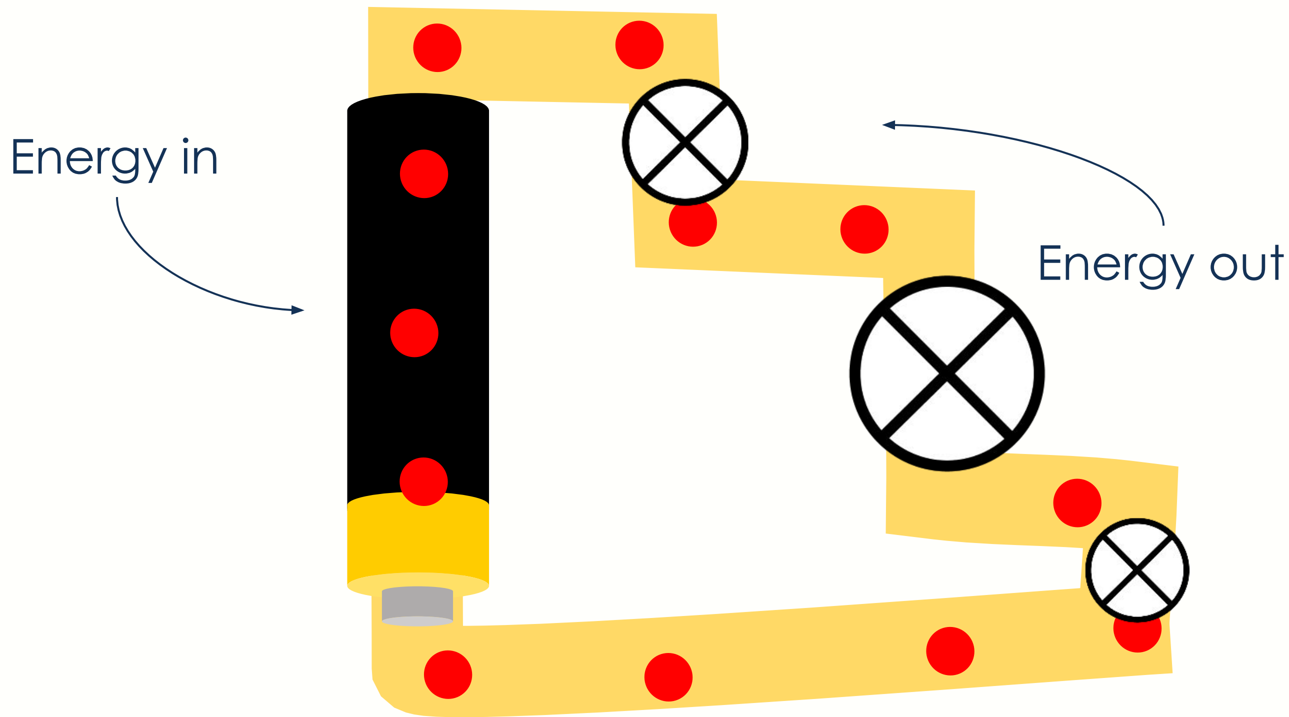
Penguins: Electrons

GPE: Electrical Energy

Friction: Resistance

Starter: Link to Real Circuit

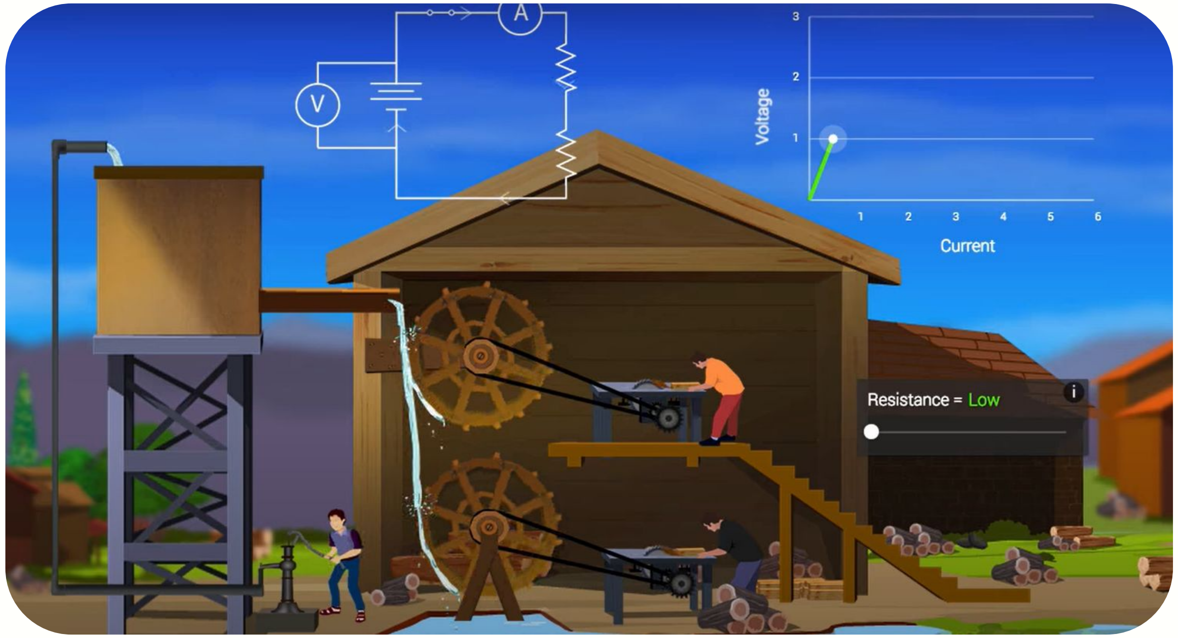




As the marbles literally drop they lose GPE.

By analogy we talk about a 'voltage drop'.

Waterfall Sim



This is a bit more complicated than the penguins. **Sign up required.**

Explain the similarities and differences.

Similarity:

- Height represent electrical energy

Differences:

- There are parallel setups
- Component are modelled

Chain

How is a bicycle chain like a circuit.

How is better than the water analogy?

The rider: cell

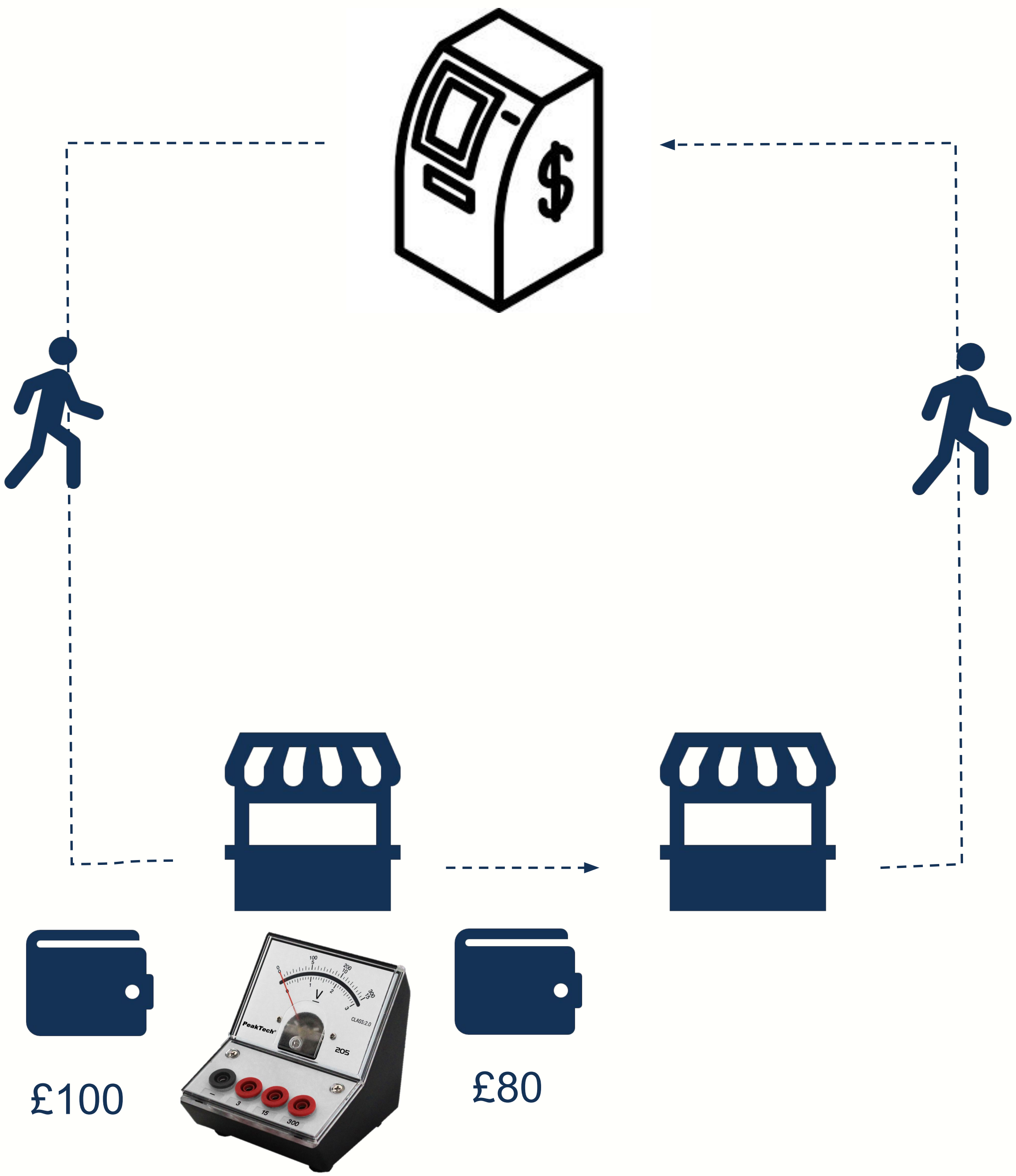
Chain: current

Back wheel: component

One advantage is the chain is definitely not used up or discarded like the water.

Also, if the load changes the rider feels it instantly.

Cash Point and Shop Analogy



This analogy captures the idea of voltage nicely.

If you nosily look in someone's wallet before and after they go in a shop, you can work out how much they spent.

This is exactly what a voltmeter does.

Remember voltage is Joules per Coulomb.

In this analogy it would be £ per person.

Analogy Summary

All of the analogies we have looked at have pros and cons.

Try and get something from all of the them.

None is exactly like the real thing.

Calculation 1

What is resistance if current is 68.3 mA and Voltage is 4.1 kV?

Step	Detail
Identify	R = ? V = 4.1 kV I = 68.3 mA
Match	V = 4,100 V I = 0.0683 A
Formula	V = IR
Arrange	R = V ÷ I
Substitute	R = 4,100 ÷ 0.0683
Total	R = 60,029 Ω = <u>60 kΩ</u>

Calculation 2

What is current if time is 3 days and charge is 23.6 kC?

Step	Detail
Identify	I = ? t = 3 days Q = 23.6 kC
Match	t = 3 × 24 × 3600 = 259,200 s Q = 23,600 C
Formula	Q = It
Arrange	I = Q ÷ t
Substitute	I = 23,600 ÷ 259,200
Total	I = <u>0.09 A</u>

Calculation 3

7.8 C does 8,800 J of work.

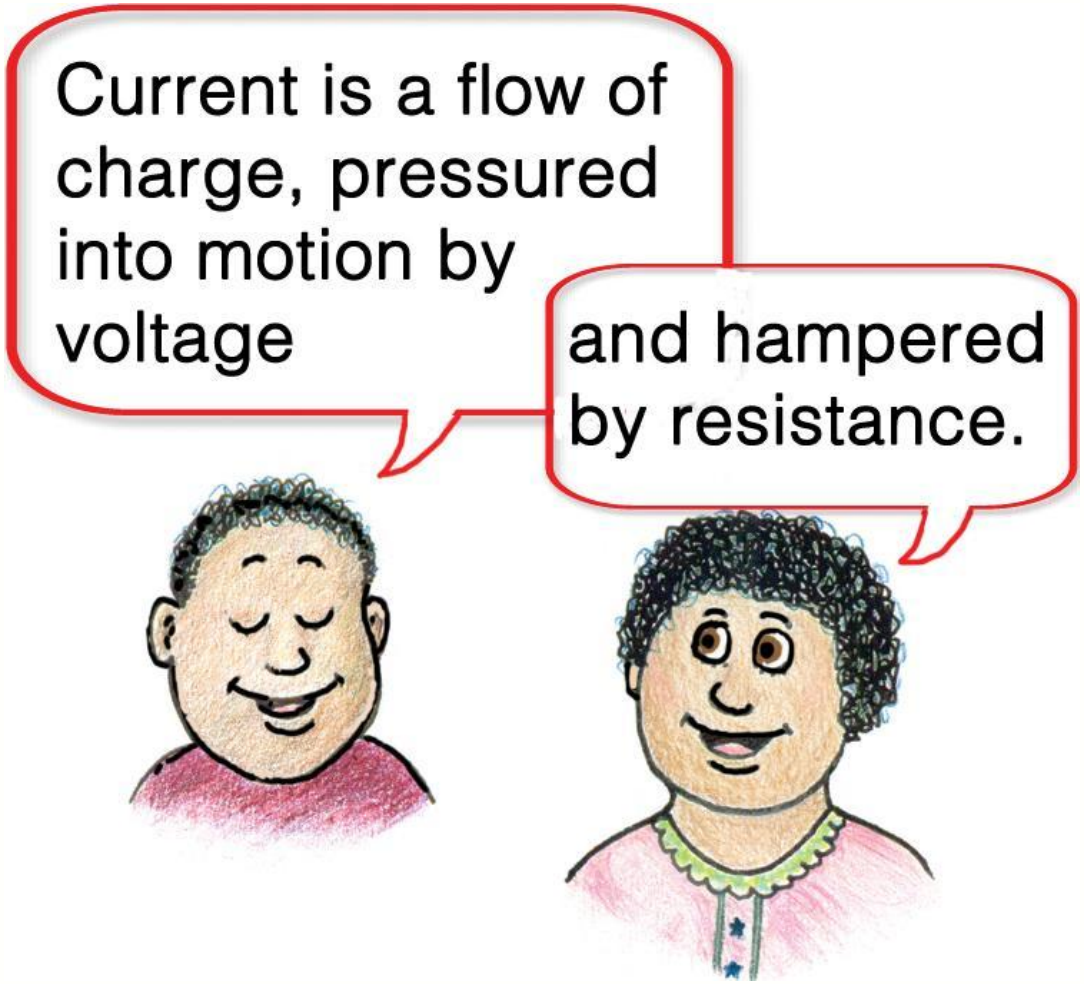
What must the voltage have been?

Step	Detail
Identify	V = ? Q = 7.8 C W = 8,800 J
Match	-
Formula	W = QV
Arrange	V = W ÷ Q
Substitute	V = 8,800 ÷ 7.8
Total	V = 1128.21 ≈ 1100 V (2sf)

Voltage vs Voltage Across

Term	Definition
Voltage	Push in a circuit Joules per Coulomb Energy per electron
Voltage across (some component)	Potential Electrical Energy Difference between two points aka Potential Difference aka P.D.

Plenary



Try and write your own summary for the topic so far.

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Explore 2: Exam Practice

Electricity – Fundamentals

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Starter

Why was the Coulomb invented?

Because electrons are ridiculously small and therefore awkwardly numerous.

Q1

A hair dryer is used for 3 minutes. The operating current is 6 A.

What charge flows in this time?

(1)

A	0.03 C
B	2 C
C	18 C
D	1080 C

Q1

Question Number	Answer	Mark
	D 1080 C	**1**
	Incorrect Answers: A – current divided by time, with the time in seconds B – current divided by time, with the time in minutes C – correct formula of current × time but the time is in minutes and not seconds	

Q2

A student is deriving an equation for the total resistance of resistors in series.

She writes the following steps but does not justify them.

Step 1 $V = V_1 + V_2$
Step 2 but $V = IR$
Step 3 so $IR = I_1R_1 + I_2R_2$
Step 4 but $I = I_1 = I_2$
Step 5 Therefore $R = R_1 + R_2$

Which step is justified using conservation of charge?

(1)

- ☐ **A** Step 1
- ☐ **B** Step 2
- ☐ **C** Step 3
- ☐ **D** Step 4

Q2

Question Number	Answer	Mark
	D Step 4	**1**
	Incorrect Answers: A – this step uses the conservation of energy B – this step is just a statement of Ohm's law C – this step uses the conservation of energy	

Q3

The current in a filament lamp is 250 mA.

How much charge flows through the lamp in 3 minutes?

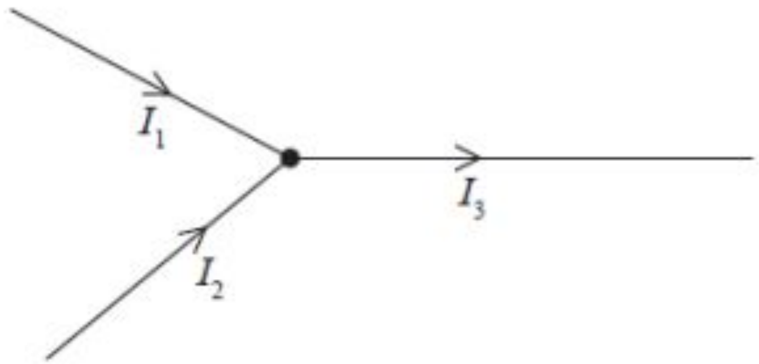
A	0.75 C
B	45 C
C	750 C
D	45,000 C

Q3

Question Number	Answer	Mark
	B	1

Q4

The diagram shows the current in part of an electrical circuit.



State the relationship between I_1, I_2 and I_3 and explain it in terms of charge.

(3)

Q4

Question Number	Answer	Mark
	$I_3 = I_2 + I_1$ (possible reference to $(Q/t)_1$ etc accepted) (1) Charge is conserved **Or** Conservation of charge **Or** charge into point = charge out of point **Or** no charge lost (1) Correct reference to same time (1) (e.g. same charge etc in same time **Or** $(Q/t)_3 = (Q/t)_1 + (Q/t)_2$ etc)	3
	Total for question	**3**

Q5

A mobile phone is powered by a lithium-ion battery. The information shown is taken from the battery.

3.82 V
6.91 W h

(i) The watt-hour (W h) is an alternative unit for energy.

Show that the maximum energy that can be stored by the battery is about 25kJ. 1 W h = 3600J

(1)

(iii) The mobile phone 'runs out of charge'.

Calculate the minimum time taken, in hours, for the battery to fully recharge.

charging current = 0.90 A

(3)

Q5

Question Number	Acceptable Answer		Additional Guidance	Mark
(i)	Use of 3600 × W h to give energy stored = 24 900 (J)	(1)	Example of calculation 6.91 W h = 6.91 × 3600 s = 24 876 J	1

Question Number	Acceptable Answer		Additional Guidance	Mark
(ii)	• Use of $V = W/Q$ • $Q = 6510$ C	(1) (1)	Example of calculation $Q = \frac{24\,876 \text{ J}}{3.82 \text{ V}} = 6512$ C (ecf for calculated energy from (a)(i)) (show that value gives $Q = 6545$ C)	2

Question Number	Acceptable Answer		Additional Guidance	Mark
(iii)	• Use of $Q = It$ Or $W = VIt$ • Use of $\frac{\text{time in seconds}}{3600}$ • $t = 2.0$ (h)	(1) (1) (1)	Example of calculation $t = \frac{6512 \text{ C}}{0.9 \text{ A}} = 7235.6$ s $t = \frac{7235.6 \text{ s}}{3600} = 2.01$ h (ecf for calculated charge from (a)(i)) (show that value gives $t = 2.02$ h)	3

Q6

Electric current in a circuit can be considered to be

☐ **A** energy transferred per unit time.

☐ **B** the rate of flow of charge.

☐ **C** the total charge flowing.

☐ **D** work done per unit charge.

(Total for question = 1 mark)

Q6

Question Number	Answers	Additional Guidance	Mark
	B	the rate of flow of charge.	**(1)**

Plenary: Taboo

Play Taboo with any word from the learning objectives.

Describe the word without using any of the others in the learning objectives.

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Explore 3: Practical

Electricity – Fundamentals

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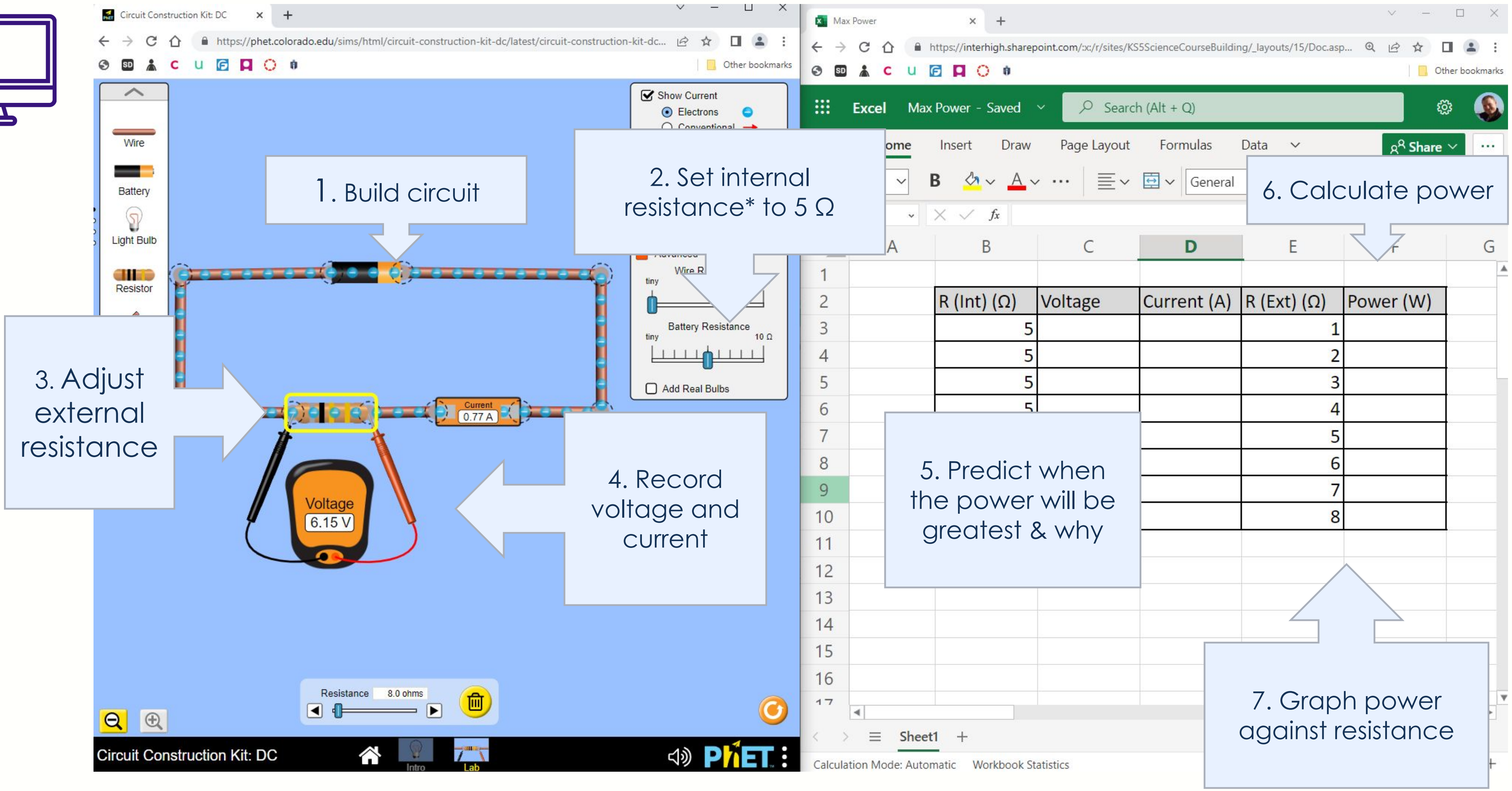
Starter

List the as many quantities as you can related to electricity including their symbols and units.

CONCEPT	NAME	UNIT
Ability to do	Energy (E)	Joule (J)
Change	Time (t)	Second (s)
Electrons	Charge (Q)	Coulomb (C)
Flow	Current (I)	Amp (A or C/s)
Push	Voltage (V)	Volt (V or J/C)
Energy Rate	Power (P)	Watt (W or J/s)
Obstacle	Resistance (R)	Ohm (Ω or V/A)

Practical: Max Power



*we will return to internal resistance in week 13, for the moment just think of it as making the circuit more realistic.

Result

R (Int) (Ω)	Voltage	Current (A)	R (Ext) (Ω)	Power (W)
5	1.67	1.67	1	2.79
5	2.86	1.43	2	4.09
5	3.75	1.25	3	4.69
5	4.44	1.11	4	4.93
5	5.00	1.00	5	5.00
5	5.45	0.91	6	4.96
5	5.83	0.83	7	4.84
5	6.15	0.77	8	4.74

As resistance increases the external resistor gets a greater share of voltage.

However, more resistance means less current.

There is a trade off between the two so the graph peaks.

Plenary

Which statement(s) are correct?

A. Voltage is proportional to resistance

B. Voltage is inversely proportional to current

C. Current is proportional to voltage

D. Current is proportional to resistance

E. Current is inversely proportional to resistance

Correct answers: C and E

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Explore 4: Exam Practice

Electricity – Fundamentals

Explore 4 Objective

Apply ideas in an exam context

Starter

Calculate the mass of electrons in the human body.

Assume

- Mass of 70 kg
- To a first order approximation humans are made of oxygen
- All atoms are the most common isotope: oxygen-16
- Use the data sheet to find the values of e_m and u.

Mass of one O atom $= 1.66 \times 10^{-27}$ kg $\times 16 = 2.66 \times 10^{-26}$ kg

Number of O atoms $= 70 \div 2.66 \times 10^{-26} = 2.64 \times 10^{27}$

Electrons per O atom = 8

Total electrons $= 8 \times 2.64 \times 10^{27} = 2.12 \times 10^{28}$

Total electron mass $= 2.12 \times 10^{28} \times 9.11 \times 10^{-31}$ kg $= 0.019$ kg = **19 g**

Q1

Q11. A current of 0.2 A flows through a lamp for 3 hours.

The total charge passing through the lamp in this time is

☐ **A** 2160 C

☐ **B** 600 C

☐ **C** 36 C

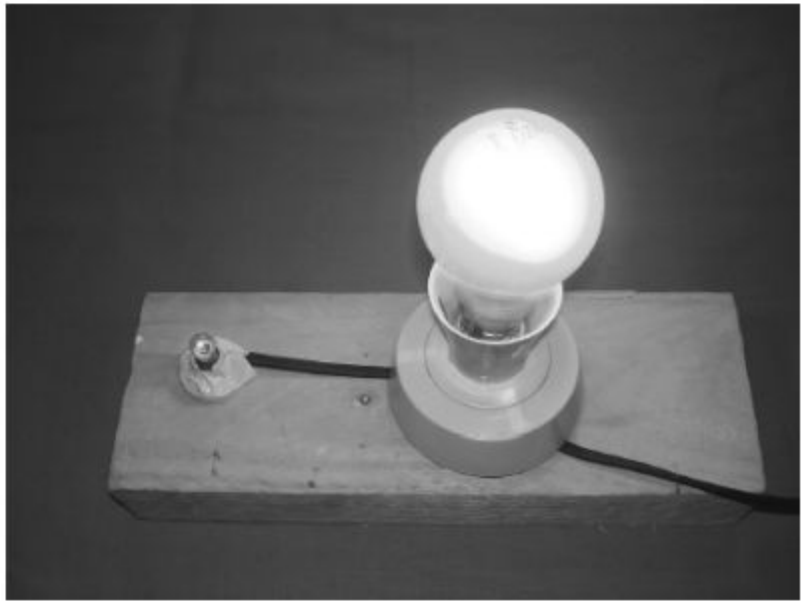
☐ **D** 0.6 C

(Total for Question = 1 mark)

Q1

Question Number	Answer	Mark
	A	**1**

Q2



The photograph shows a piece of apparatus in which a mains light bulb and a torch bulb are both connected to the mains.

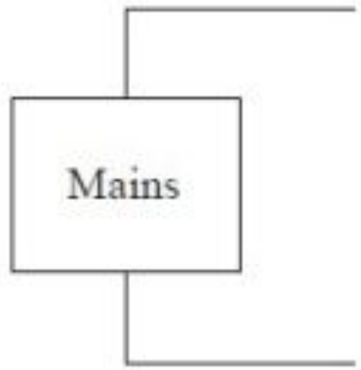
Students were surprised to see both bulbs shining normally when the apparatus was switched on.

It is impossible to tell from looking at the apparatus whether the bulbs are connected in series or in parallel.

To test this, the apparatus was switched off and the mains bulb was removed. When it was switched on again the torch bulb did not light up. When this was repeated, removing the torch bulb, the mains bulb did not light up.

When the circuit was tried again with both bulbs, they still operated normally.

(a) Complete the circuit diagram to show how the bulbs are connected and explain why they must be connected in this way and not the alternative.



(3)

Q2

Question Number	Answer	Mark
(a)	Series sketch with two bulbs **(1)** Connected in series: because when one is removed there is a break in the circuit **Or** because when one is removed there is no current **Or** so the bulbs could have different p.d.s **(1)** Not connected in parallel because: if one removed, still complete circuit (for the other) **Or** if one removed, still current (through the other) **Or** full mains voltage would have blown small bulb **(1)**	**3**

Q2

Question Number	Answer	Mark
(a)	Series sketch with two bulbs **(1)** Connected in series: because when one is removed there is a break in the circuit **Or** because when one is removed there is no current **Or** so the bulbs could have different p.d.s **(1)** Not connected in parallel because: if one removed, still complete circuit (for the other) **Or** if one removed, still current (through the other) **Or** full mains voltage would have blown small bulb **(1)**	**3**

Q2

(b) The mains bulb is marked 40 W, 230 V.

(i) Show that the current in the mains bulb is about 0.2 A when it is operating normally.

Q2

(b) (i)	Use of $P = IV$ $I = 0.17$ (A) (at least 2 sf required) <u>Example of calculation</u> $40\ \text{W} = I \times 230\ \text{V}$ $I = 0.17\ \text{A}$	(1) (1)	2

Q2

(ii) Calculate the resistance of the mains bulb when it is operating normally.

(2)

(iii) The torch bulb is marked 2.5 V, 0.20 A.

Calculate the resistance of the torch bulb when it is operating normally.

(2)

(iii) The torch bulb is marked 2.5 V, 0.20 A.

Calculate the resistance of the torch bulb when it is operating normally.

(2)

(c) Explain, with reference to both current and potential difference, why it is possible to operate both bulbs at the same time from the same power supply.

(2)

(d) Earlier in the question you were asked to calculate the resistances of the bulbs when operating normally.

Explain the effect on the resistances of the bulbs if they are operated at a much smaller current so that neither bulb lights up.

(4)

Q2

(b)(ii)	Use of appropriate equation $R = 1300\ \Omega$ <u>Example of calculation</u> $P = V^2/R$ $40\ \text{W} = (230\ \text{V})^2 / R$ $R = 1323\ \Omega$	**(1)** **(1)**	**2**
(b)(iii)	Use of $R = V/I$ $R = 13\ \Omega$ <u>Example of calculation</u> $R = 2.5\ \text{V} / 0.2\ \text{A}$ $R = 12.5\ \Omega$	**(1)** **(1)**	**2**
(c)	Current – both require about the same (not just both have 0.2 A) Potential difference – total (required) p.d. is very close to mains supply **Or** (operating) p.d. for mains bulb much greater than (operating) p.d. for torch bulb	**(1)** **(1)**	**2**

Q3

Q14. Explain why an ammeter

- must be placed in series to measure current through a component
- must have a very low resistance.

(3)

Q3

Question Number	Answer		Mark
	current same in series **Or** current is different if not in series to ensure the total resistance in the circuit isn't increased **Or** to ensure no pd lost because that would reduce the current being measured [Just saying current changes or resistance changes is not sufficient for MP2 and 3. Candidates who **only** refer to what would happen if ammeter in parallel can only score MP1]	(1) (1) (1)	3
	Total for question		**3**

Q4

An ampere can be expressed as

- ☐ **A** $C\ s^{-1}$
- ☐ **B** $J\ C^{-1}$
- ☐ **C** $V\ W^{-1}$
- ☐ **D** $V\ \Omega$

Q4

Question Number	Answer	Mark
	A	1

Q5

Which of the following is a correct unit for resistance?

- ☐ **A** $J\,C^{-1}$
- ☐ **B** $V\,C^{-1}\,s^{-1}$
- ☐ **C** $J\,C^{-2}\,s$
- ☐ **D** $J\,C^{-2}\,s^{-1}$

Q5

Question Number	Answer	Mark
	C	1

Plenary Taboo

- Play Taboo with any word from the learning objectives.
- Describe the word without using any of the others in the learning objectives.

Lesson complete!

See you next lesson