B1 · Charge and charging

Completed notes

Explain charge, draw charge separation, and predict the result of contact or grounding.

Slide 1 of 8 · Charge is carried by electrons

A rubbed balloon sticks to a wall. Unit B explains why. We start with what carries charge.

Atoms have **protons** (+) in the nucleus and **electrons** (−) around it. One electron has charge size e = **1.60×10^{-19} C**. C is the **coulomb**, the unit of charge.

Neutral: **equal** protons and electrons, so the charges cancel. Only **electrons** move; protons stay in the nucleus.

Gain electrons: **negative**. Lose electrons: **positive**. Charge is **conserved**: it moves, and is never made or lost.

Charge comes in whole electrons: Q = **ne**. n is a count, with no sign. Find the size, then add the **sign**.

Example. A neutral plastic rod is rubbed with wool and gains 2.5×10^{13} electrons from the cloth. What is the charge on the rod, with its sign? Use e = 1.60×10^{-19} C.

1. The rod gained electrons, so its charge is negative.

2. Q = ne = $(2.5 \times 10^{13})(1.60 \times 10^{-19}\ \text{C}) = 4.00 \times 10^{-6}$ C

3. Charge on the rod: −4.00 µC (1 µC = 10^{-6} C).

Try it. A glass rod is rubbed with silk and ends with a charge of +3.2 µC. How many electrons did the glass rod lose, and where did they go?

1. The glass is positive, so it lost electrons. They went to the silk, which has a charge of −3.2 µC.

2. Change µC to C first: 3.2 µC = 3.2×10^{-6} C.

3. n = Q/e = $(3.2 \times 10^{-6}\ \text{C}) \div (1.60 \times 10^{-19}\ \text{C}) = 2.0 \times 10^{13}$ electrons.

Slide 2 of 8 · Conductors, insulators and rubbing

On slide 1, only electrons moved. Where they can move depends on the material.

In a metal, some outer electrons are **free** and roam the whole object. Metals are **conductors**. In plastic, glass, rubber and wool, electrons stay with their atoms. These are **insulators**.

Extra electrons repel each other. On a metal they **spread out**. On plastic they stay **where you put them**.

Rubbing moves electrons, because materials hold electrons with different strengths. The weaker holder loses electrons and turns **positive**. The other turns **negative** by the **same amount**.

On the diploma, explain a result by saying which way the **electrons** moved.

Example. A plastic ruler is rubbed with a wool cloth and the ruler becomes negative. No protons moved. What is the sign of the charge on the wool, how do the two sizes compare, and which material holds electrons more strongly?

1. The ruler gained electrons and they came from the cloth, so the wool is positive.

2. The two charges have equal size and opposite sign, so the total stays zero (charge is conserved).

3. The plastic holds electrons more strongly, because the electrons moved to it.

Try it. A student rubs a metal rod with a cloth while holding the rod in a bare hand. Brought near bits of paper, it does nothing. Explain why, and say what could be changed so the rod keeps its charge.

1. The metal rod, hand, body and floor all conduct, so the extra electrons flow away to the ground and the rod stays neutral.

2. An insulating handle breaks the path, so the rod keeps its charge.

Slide 3 of 8 · Why a neutral object is attracted

A charged rod also pulls on objects that have no charge. Slide 2 helps explain why.

A negative rod near a neutral metal sphere: like charges repel, so free electrons move to the **far** side. The near side is short of electrons, so it is **positive**.

This shift is charge **separation**. It ends when the rod leaves. The sphere is still **neutral**. No electrons left it.

Unlike charges attract, and the near side is **closer**, so attraction is **stronger**. The sphere is pulled toward the rod.

Attraction alone **does not** prove an object is charged. Only **repulsion** proves it.

Example. A negative rod is held near, but not touching, a neutral metal sphere on an insulating stand. What is the sign of the charge on the side nearest the rod, what is the total charge of the sphere, and does the sphere move toward or away from the rod?

1. The electrons are pushed to the far side, so the near side is positive.

2. The total charge is still zero.

3. The sphere is pulled toward the rod, because the positive side is closer.

Try it. A charged rod attracts a small object hanging from a thread. Which statement must be true? A. The object has a charge opposite to the rod. B. The object is neutral. C. The object may be neutral or have a charge opposite to the rod. D. The object has the same charge as the rod.

1. Answer C.

2. A neutral object is also attracted, because its charges separate, so attraction does not prove an opposite charge.

3. Repulsion is the only test that proves the object is charged with the same sign as the rod.

Slide 4 of 8 · Charging by contact and sharing

So far the rod only came near an object. Now two metal spheres touch.

Touching conductors share charge. If the stands are **insulators**, no charge can enter or leave, so the **total** stays the same.

Identical spheres (same size and shape) end with **equal** charge: $q = \mathbf{(q_1 + q_2) \div 2}$.

Add the charges **with their signs** first, then divide by two. The final sign is the sign of **both spheres**.

Sketch the problem three times: **before**, **during** and **after**, with each charge written beside its sphere. Check that the total after equals the total **before**.

Example. Two identical metal spheres carry +7.0 µC and −3.0 µC. They touch and are then separated. What is the charge on each sphere after the separation?

1. Total = (+7.0 µC) + (−3.0 µC) = +4.00 µC.

2. Identical spheres share equally: each ends with +2.00 µC.

3. Check: +2.00 + 2.00 = +4.00 µC, the same as the total before.

Try it. Three identical spheres A, B and C carry +9.0 µC, 0 and −3.0 µC. A touches B and they separate. Then B touches C and they separate. What is the final charge on each of A, B and C?

1. First touch: A and B each have (9.0 + 0) ÷ 2 = +4.50 µC. C is untouched at −3.0 µC.

2. Second touch: B and C each have (4.5 + (−3.0)) ÷ 2 = +0.750 µC. A stays at +4.50 µC.

3. Check: 4.50 + 0.750 + 0.750 = +6.00 µC, the same as the start.

Slide 5 of 8 · Method: how to find the charge after spheres touch

These are the steps you used on slide 4.

Step 1: write each charge **with its sign**. Step 2: **add** the signed charges. Step 3: divide by the **number of identical spheres**.

Step 4: give **every sphere** that charge, with its sign. Step 5: check that the total after is **the same as** the total before.

Example. Two identical metal spheres carry +7.0 μC and −3.0 μC. They touch and are then separated. Use the five steps to find the charge on each sphere.

1. Steps 1 and 2: (+7.0) + (−3.0) = +4.00 μC.

2. Step 3: (+4.00) ÷ 2 = +2.00 μC.

3. Steps 4 and 5: each sphere has +2.00 μC, and +2.00 + 2.00 = +4.00 μC matches the total before.

Try it. NEW, for teacher review: Two identical spheres carry +5.0 μC and −9.0 μC. They touch and are separated. What is the charge on each sphere?

1. Steps 1 and 2: (+5.0) + (−9.0) = −4.00 μC.

2. Step 3: (−4.00) ÷ 2 = −2.00 μC.

3. Each sphere has −2.00 μC. Check: −2.00 + (−2.00) = −4.00 μC, the same as before.

Slide 6 of 8 · Grounding and induction

On slide 3 the shift ended when the rod left. A path to the Earth lets the sphere keep a charge.

The Earth is so large that it can give or take any number of electrons and stay neutral. A wire or conducting path to the Earth is called a **ground**.

Induction means charging an object **without touching it** with the charged object. Steps in order: 1. bring the rod **near**; 2. connect the **ground**; 3. remove the **ground** wire; 4. remove the **rod**.

A negative rod pushes electrons away, so they leave through the ground and the sphere ends **positive**. A positive rod pulls electrons up from the ground and the sphere ends **negative**.

Contact gives the **same** sign as the rod. Induction gives the **opposite** sign. The shift while the rod is near is charge **separation**; the charge left is **induced** charge. Remove the ground wire first so the charge is trapped; if the rod leaves first, electrons **flow back**.

Example. A positive rod is brought near, but never touches, a neutral metal sphere on an insulating stand. The sphere is grounded with a wire. The ground wire is removed first, and then the rod. What is the sign of the charge left on the sphere, and where did the charge come from?

1. Electrons were attracted from the ground into the sphere and trapped there when the ground wire was removed.

2. The sphere is left negative, the sign opposite to the rod.

Try it. A neutral metal sphere on an insulating stand is to be given a positive charge using a negative rod. Which option does this? A. Touch the rod to the sphere, then remove the rod. B. Rod near, connect ground, remove rod, remove ground. C. Rod near, connect ground, remove ground, remove rod. D. Rod near, remove rod, connect ground.

1. Answer C. The negative rod pushes electrons from the sphere into the ground. The ground is removed first, so they cannot return, and the sphere stays positive when the rod is removed.

2. A charges the sphere negative by contact. B removes the rod while still grounded, so electrons return and the sphere is neutral. D grounds after the rod has gone, so the sphere is neutral.

Slide 7 of 8 · The electroscope

We cannot see electrons shift inside a metal. This tool shows it.

An electroscope is a metal **knob** joined by a metal rod to two thin metal **leaves**. Electrons can move between the knob and the leaves. When it is neutral the leaves hang **together**.

A negative rod near the knob pushes electrons **down** to the leaves. Both leaves are **negative**, so they **repel** and spread apart. A positive rod pulls electrons **up**, so both leaves are **positive** and they spread apart too.

A neutral electroscope shows that a charge is **near**. It cannot show the **sign**. Touch the knob with a charged rod and the leaves **stay apart**: charging by contact. Touch the knob with a finger and the leaves **fall**: it is grounded.

On a charged electroscope, an object with the **same** sign makes the leaves spread more. An object with the **opposite** sign makes them move closer together.

Example. An electroscope has been charged negative by contact, so its leaves stand apart. Charged object X is held near the knob, without touching it, and the leaves move farther apart. X is taken away. Charged object Y is held near the knob, without touching it, and the leaves move closer together. What is the sign of the charge on X, and on Y? Explain each answer with the movement of electrons.

1. X is negative. It repels electrons from the knob down to the leaves. The leaves become more negative, so they repel more and move farther apart.

2. Y is positive. It attracts electrons from the leaves up to the knob. The leaves become less negative, so they repel less and move closer together.

Try it. NEW, for teacher review: An electroscope has been charged positive by contact, so its leaves stand apart. Charged object Z is held near the knob, without touching it, and the leaves move farther apart. What is the sign of the charge on Z? Explain with the movement of electrons.

1. Z is positive. It attracts electrons from the leaves up to the knob.

2. The leaves lose electrons, so they become more positive. They repel more and move farther apart.

Slide 8 of 8 · Method: how to explain a charging result in words

Use these steps for any “explain the charge” question in this lesson.

Step 1: name the object and say whether it is a **conductor**. Step 2: say which way the **electrons** move. Step 3: say what each object **gains or loses**.

Step 4: state the final sign. Gaining electrons gives **negative**; losing electrons gives **positive**. Step 5: say the total charge **did not change**.

Example. A positive rod is brought near a neutral metal sphere on an insulating stand. The sphere is grounded, the ground is removed, and then the rod is removed. Explain the final charge on the sphere.

1. 1: The sphere is metal, so electrons can move through it.

2. 2 and 3: The rod attracts electrons up from the ground, so the sphere gains electrons.

3. 4 and 5: The ground left first, so the sphere is negative, and the total charge did not change.

Try it. NEW, for teacher review: A neutral metal sphere on an insulating stand touches a negative rod. Explain the sign of the charge on the sphere.

1. 1: The sphere is metal, so electrons can move.

2. 2 and 3: Electrons move from the rod to the sphere, so the sphere gains electrons.

3. 4 and 5: The sphere is negative, and the total charge of rod and sphere did not change.

B1 · Worked practice

Charge and charging | Questions 1-2 of 12

Use $k = 8.99 \times 10^9$ N·m²/C² and $g = 9.81$ m/s² where needed. These values are from the Alberta Physics 30 data sheets, Constants section. All point-charge calculations approximate air as vacuum.

Easy · B1-P01. An object has 8 protons and 10 electrons, each with a charge of the same size. What is the object's total charge in units of e, and what electron change would make it neutral?

1. Count both kinds of charge: +8e + (−10e) = −2e. The object is negative because it has two extra electrons.

2. Remove two electrons. That leaves 8 protons and 8 electrons, so the charges balance. The protons do not need to move.

Easy · B1-P02. A neutral metal sphere loses electrons to another object. What is its final sign? Describe the change in the total charge of the two objects together.

1. Electrons carry negative charge. Losing them leaves an electron deficit, so the sphere becomes positive.

2. The other object gains the electrons. Its charge changes by the same amount with the opposite sign. The total charge of the two objects stays the same.

B1 · Worked practice

Charge and charging | Questions 3-4 of 12

Easy · B1-P03. Extra charge spreads across a metal object but stays near the rubbed spot on a plastic object. Which is the conductor and which is the insulator? Explain using charge motion.

1. The metal is the conductor: its free electrons can move through the material.

2. The plastic is the insulator: it resists charge flow through the object. This does not mean it cannot be charged or have its charges separated.

Easy · B1-P04. A known negative object repels a small charged object. What is the sign of the small object? If the observation were attraction instead, could you be certain it was positive? Explain.

1. Repulsion between the charged objects indicates like signs, so the small object is negative.

2. Attraction alone is not enough to decide. A positive object would be attracted, but a neutral object can also be attracted when its charges separate.

B1 · Worked practice

Medium · B1-P05. A positive rod approaches the left side of a neutral metal sphere on an insulating stand without contact. Draw the sphere’s near-side and far-side charge signs, the electron-motion arrow, and its total charge. Explain the attraction.

1. The positive rod attracts free electrons toward the left, nearer side. Draw an electron arrow left within the sphere; label the near side negative and far side positive.

2. No charge enters or leaves the sphere, so its total charge stays zero. The closer negative side is attracted more strongly than the distant positive side is repelled. The net force is toward the rod.

Medium · B1-P06. Two identical metal spheres on insulating supports have +8.0 µC and −2.0 µC. They touch and are separated far apart. No charge escapes. What is each final charge, and which way did electrons move?

1. Givens from the question: qA = +8.0 µC and qB = −2.0 µC; identical spheres on insulating stands. Conservation applies because no charge escapes.

2. Total = +8.0 + (−2.0) = +6.0 µC. In the case of identical spheres, each gets +6.0/2 = +3.0 µC.

3. Electrons move from B toward A. A becomes less positive while B loses electrons and becomes positive. Check: +3.0 + 3.0 = +6.0 µC.

B1 · Worked practice

Medium · B1-P07. A negative rod is held near a neutral metal sphere. The sphere is grounded, the ground is disconnected, and then the rod is removed. What is the final sign? Draw the electron path during grounding and explain the order.

1. The negative rod repels free electrons. Ground provides a conducting path, so electrons leave the sphere and enter Earth. Draw sphere → Earth and label it electron flow.

2. Disconnecting ground while the rod remains traps the electron deficit. Removing the rod then allows the remaining charge to redistribute. The final sphere is positive.

3. The rod never touches the sphere. This is charging by induction, with charge transferred through the ground connection.

Medium · B1-P08. A positive rod is brought near a neutral metal sphere on an insulating stand, then removed. There is no contact or grounding. What are the sphere’s total charge while the rod is near and after it leaves? Explain where the charges sit at both times.

1. While the rod is near, electrons move toward it: the near side is negative and the far side positive. The sphere’s total charge is zero because no charge enters or leaves.

2. After the rod leaves, the electrons redistribute without the rod’s influence. The sphere remains neutral. Separation within one object is different from moving charge on or off it.

B1 · Worked practice

Charge and charging | Questions 9-10 of 12

Challenging · B1-P09. Sphere A starts at +10.0 µC, sphere B at −4.0 µC and sphere C at 0 µC. All are identical metal spheres on insulating supports. A touches B, then they separate far apart. B then touches C and they separate far apart. No charge escapes. What is each final charge? Check the total.

1. For the first contact, A + B = +10.0 - 4.0 = +6.0 µC. Identical spheres share equally: A = +3.0 µC and B = +3.0 µC. C is still zero.

2. Only B and C participate in the second contact. Their total is +3.0 µC, so B = C = +1.5 µC. A stays +3.0 µC.

3. Final: A = +3.0 µC, B = +1.5 µC, C = +1.5 µC. The sum is +6.0 µC, equal to the initial total. Dividing the initial total among all three would ignore the contact sequence.

Challenging · B1-P10. A student charges a sphere using a negative rod and ground, but removes the rod while the ground wire is still attached. The rod is moved far away before the ground is disconnected. What is the final charge? Explain why this differs from the correct induction sequence.

1. With the negative rod nearby, electrons are driven from the sphere to Earth. The sphere has an electron deficit while influenced by the rod.

2. Removing the rod first removes that influence while the conducting Earth path remains open. Electrons can return from Earth, making the sphere neutral.

3. Disconnecting ground afterwards leaves a neutral sphere. To retain positive charge, disconnect ground before removing the negative rod.

B1 · Worked practice

Charge and charging | Questions 11-12 of 12

Challenging · B1-P11. A student says, “A neutral plastic comb cannot be attracted to a charged rod because electrons cannot move freely through plastic.” Identify the error. Draw or describe what the charges inside the comb do to explain the attraction without giving the comb a total charge.

1. The error is treating resistance to charge flow through the object as the inability of any charge to shift. The charges inside an insulator’s atoms or molecules can shift slightly.

2. Draw a negative rod beside several neutral particles. In each particle, show the negative charge shifted slightly away from the rod and the positive side nearer the rod. Each particle and the whole comb remain neutral.

3. The nearer opposite charge is attracted more strongly than the more distant like charge is repelled. This charge separation can attract the comb without giving it a total charge.

Challenging · B1-P12. Two metal objects of different sizes with charges +8.0 µC and −2.0 µC touch, and no charge can enter or leave. A student predicts +3.0 µC on each. Which part of the prediction is guaranteed, which is not, and what extra condition would justify equal sharing?

1. Charge conservation guarantees a final combined total of +6.0 µC. Adding the signed initial charges is valid even when the objects differ.

2. Equal final charges are not guaranteed for unequal conductors. Their shapes affect how the charge is shared.

3. The +3.0 µC-each result is justified for identical conducting spheres, separated far apart afterwards. Conservation alone does not justify dividing by two.