UNIT 4 Moving Charges

Recommended Prior Knowledge
Pupils will need to have encountered electrons and should know where they are to be found in the atom. Pupils are likely to have some basic understanding of electrostatic charging and this will be useful in coming to grips with electric charge in a more general manner. That charge comes in two distinct types which may cancel out is also worth explaining as, frequently, it is just assumed to be true. It would be useful if pupils had encountered the idea of electric current in some domestic or more elementary way before it is properly defined here.

Context
This very substantial unit is an absolutely essential preliminary for the topics which are met in units 7 and 10. Electricity is a major constituent of any physics course and it is here that the most fundamental ideas are initially explained. Pupils do not find these ideas easy or self-evident and so this unit needs to be tackled with particular care.

Outline
The early sections deal with electrostatic charge and some situations in which it is found. The fundamental link between charge and electrons is made explicit at this stage. The electric field can be treated as another field of force and the idea of force lines can be introduced quite naturally with it. The distinction between conductors and insulators is drawn and this leads directly into the relationship between charge and current. The ampere is defined in some imprecise way at this point. This opens up the topic of electrical circuits and all the fundamental ideas follow from the concept of an electric current. E.m.f. and p.d. are introduced, and power and resistance are defined here. Pupils will also become very familiar with circuit diagrams and the symbols for many essential conducting components. This is a large and important unit and it should not be rushed.

	Learning Outcomes	**Suggested Teaching Activities**	**Online Resources**	**Other resources**
18(a)	Describe experiments to show electrostatic charging by friction.	Use a rubbed, insulating rod to deflect a trickle of water, make hair stand on end, pick up dust and small pieces of paper. Rub a balloon and it sticks to the wall. Recall that clothing sticks to your back on dry days, that walking on nylon carpets, leaving cars and touching TV screens causes small electric shocks. A tingling sensation is felt before lightning storms. Use local examples with which the pupil will be familiar as climate has an effect.	Theatre of Electricity: http://www.mos.org/sln/toe/toe.html Van de Graaf Generator: http://www.howstuffworks.com/vdg.htm	Use a Van de Graaf generator to show electrostatic effects. **This high voltage device must only be used by a qualified operator and under conditions of the strictest safety.**
18(d)	State that unlike charges attract and that like charges repel.	These effects are most easily shown by balancing charged rods on a lens or watch glass.	The Gold-Leaf Electroscope: http://www.glenbrook.k12.il.us/gbssci/phys/mmedia/estatics/esn.html	Use a gold-leaf electroscope to show repulsion of the leaf.

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18(c)	State that there are positive and negative charges and that charge is measured in coulombs.	Use several different charged rods. There are only two types of behaviour and only two types of charge. Use two rods of different materials together to show a reduced effect. One type of charge cancels the other and so they may be called positive and negative.	Types of Charge: http://www.bbc.co.uk/schools/gcsebitesize/physics/electricity/electricchargeandcurrentrev4.shtml	Set up a series circuit with an EHT supply, two separated metal plates and a very sensitive galvano-meter or coulombmeter. A table-tennis ball (with a conducting coating) shuttles between the two plates and a reading is recorded. **The high voltage EHT supply must only be used by a qualified operator and under conditions of the strictest safety.**
18(b)	Explain that charging of solids involves a movement of electrons.	State this as a fact. Pupils have probably heard of electrons (even if unit 3 has not been taught) and know they are negative. Emphasise that the negative charges move and that positive objects have lost electrons.	Charging by friction: http://www.glenbrook.k12.il.us/gbssci/phys/Class/estatics/u8l2a.html	A can containing a duster is on a gold-leaf electroscope. Take a nylon rod from the can which rubs against the duster. The leaf deflects. Reinsert the rod. The deflection collapses.
18(e)	Describe an electric field as a region in which an electric charge experiences a force.	Emphasise the idea that actions occur near to a charged object: pick up small pieces of paper, dust on polished glass, clothing sticks to back, and crackling near overhead power cables.	Electric field: http://hyperphysics.phy-astr.gsu.edu/hbase/electric/elefie.html	
18(f)	State the direction of lines of force and describe simple field patterns.	Plot field patterns with EHT supply, electrodes and semolina grains in cooking oil. **The high voltage EHT supply must only be used by a qualified operator and under conditions of the strictest safety.** Avoid comparing electric and magnetic fields at this early	Plotting field patterns: http://www.physicslab.co.uk/Efield.htm Electric Fields: http://www.colorado.edu/physics/2000/waves_particles/w	Pupils can become adept at drawing electrostatic fields. Give them a few rules: • Field lines do not cross. • Field line leave

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		stage, it confuses.	[avpart3.html]	conductors at right angles. • Arrows point from + to - . Try: ball to ball, plate to plate, ball to plate, cloud to city skyline/trees/cars.
18(g)	Describe the separation of charges by induction.	Two metal balls on insulating stands are touching. Bring a rod near to **one** ball. Separate the balls and check the charges using a gold-leaf electroscope. Charge a gold-leaf electroscope itself by induction.	Electrostatic Induction: http://www.physics.ncsu.edu/courses/py208/208animations/induction.html	
18(h)	Describe the differences between electrical conductors and insulators and state examples of each.	Use a low voltage d.c. circuit with a lamp to test common materials. Try to discharge a gold-leaf electroscope through these common materials. Can the charge pass through people? **Do not try to pass electric currents through people.** Pupils will see that the best conductors are metals.	Conductors and insulators: http://www.ndt-ed.org/EducationResources/HighSchool/Electricity/conductorsinsulators.htm	Notice that wood does not conduct a current but does discharge an electroscope. **Never use a wooden object to rescue someone who is being electrocuted.**
18(i)	State what is meant by "earthing" a charged object.	Standing on a rubber sheet or plastic bag and repeat.		
18(j)	Describe examples where charging could be a problem e.g. lightning.	Spark hazard: (1) On oil tankers sailors wear special conducting shoes. (2) Aeroplanes and filling station tanks are electrically connected to the tanker when being filled with fuel. (3) Small shocks in cars or large carpeted shops.	Lightning: http://www.fi.edu/weather/lightning/lightning.html	Conductors solve these problems, e.g. • slightly conducting aeroplane tyres discharge landing planes slowly • lightning conductors.
18(k)	Describe examples where charging is helpful e.g. photocopier and electrostatic precipitator.	Explain how these devices work. Pupils can be given sheets with printed diagrams of different stages in the procedure and can label or complete them. Concentrate on the charge placed on the photosensitive	Photocopier: http://home.maine.rr.com/randylinscott/copier.htm Electrostatic Precipitator:	

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		drum surface and how light enables it to be removed. In a photocopier, a mirror image is formed twice which restores the original pattern. This is an interesting occurrence in its own right. Use as the image something which lacks left/right and top/bottom symmetry, e.g. a large letter F, L or R.	http://www.eas.asu.edu/~holbert/wise/electrostaticprecip.html Electrostatic Spraying: http://www.spraytec.com/articles/Electrostatic.htm or: http://en.wikibooks.org/wiki/Uses_of_static_electricity_%28GCSE_science%29	
19(a)	State that a current is a flow of charge and that current is measured in amperes.	Refer to the shuttling ball experiment. Set up a series circuit with an ammeter, large resistance and a coulombmeter. Plot charge → time. Use a larger current. Emphasise that a current is a "loop flow" of charge which is the **mechanism** for energy (not properly defined until unit 6) transfer. The bicycle chain is a reasonably good analogy for a current. **Use the word current rather than amperage.**	Electric Current: http://hyperphysics.phy-astr.gsu.edu/hbase/electric/elecur.html or: http://www.sunblock99.org.uk/sb99/people/DMackay/electricity.html or: http://www.schoolscience.co.uk/content/3/physics/circuits/circh1pg3.html	
20(b)	State that the current at every point in a series circuit is the same, and use this in calculations.	Allow pupils to predict how current varies at different places in a series circuit. Then allow them to test their predictions.		
20(d)	State that the current from the source is the sum of the currents in the separate branches of a parallel circuit.	Measure the current in different branches of parallel circuits. Currents split but the total remains the same. Change the resistance of some branches. Compare with water in supply pipes.		

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19(b)	Do calculations using the equation *charge = current x time.*	At this stage it is easier to define the ampere as the coulomb/second rather than the more accurate reverse. Some pupils find rearranging equations hard, even though in more everyday examples – e.g. 50 km/h for 2 h, distance travelled = 100 km – there seems to be no problem.	Current and charge: http://www.bbc.co.uk/schools/gcsebitesize/physics/electricity/electricchargeandcurrentrev5.shtml	Explain that a charged battery stores a certain amount of charge. It can supply 20 A for 2 h or 10 A for 4 h etc. A flat battery cannot supply charge.
19(c)	Describe the use of an ammeter with different ranges.	This will be covered as pupils use ammeters in different experiments. Pupils should know how to use the ammeters **they** deal with.	Using a multimeter: http://www.doctronics.co.uk/meter.htm	
19(d)	Explain that electromotive force (e.m.f.) is measured by the energy dissipated by a source in driving a unit charge around a complete circuit.	First explain that e.m.f. is the property of a source of electrical energy, include: cells, generators. If a circuit is left on for twice as long it transfers twice as much energy (unit 5). Hence energy/charge is a constant.	Definition of electrical quantities: http://monopole.ph.qmw.ac.uk/~thomas/emf/handout6.PDF	Heat water in a polystyrene cup with a low voltage (this word is hard to avoid) immersion heater. Plot temperature → time; this is equivalent to energy → charge.
19(e)	State that e.m.f. is work done/charge.	There are a variety of analogies possible for this difficult idea: The Coulomb Brothers carry sacks of joules around the circuit. They drop the joules off at the appliance and return with an empty sack.	E.m.f and p.d: http://www.patana.ac.th/parents/curriculum/Physics_K4/units/DJFPh035.html	Coal lorries travel in a continuous loop from the coal mine to the power station and travel back empty. There is a fixed amount of energy per lorry.
19(f)	State that the volt is given by J/C.	There is a fixed number of joules/coulomb.		
19(g)	Calculate the total e.m.f. where several sources are arranged in series and discuss how this is used in the design of batteries.	Carry out the measurement with a voltmeter. Consider car batteries (6 x 2.0 V) and PP9s (6 x 1.5 V). Keep a PP9 which has been sawn in half and show the six layers.	Cells in series and parallel: http://www.batteryuniversity.com/partone-24.htm	

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19(h)	Discuss the advantage of making a battery from several equal voltage sources of e.m.f. arranged in parallel.	Refer back to 20(d). Charge up a model lead-acid cell for a few minutes. Discharge it through a torch lamp and time how long it takes. Repeat with two lead cells in parallel, each of which was charged for the same time and with the same current as the previous cell.	Several cells in parallel: http://www.allaboutcircuits.com/vol_6/chpt_3/3.html	
19(i) **19(j)**	State that the potential difference across a circuit component is measured in volts. State that the p.d. across a component in a circuit is given by the work done in the component/charge passed through the component.	This can be done by referring back to the definition of e.m.f. The p.d. however, is concerned with where the energy ends up, not where it comes from.	Potential difference: http://www.regentsprep.org/Regents/physics/phys03/apotdif/default.htm	
19(k)	Describe the use of a voltmeter with different ranges.	Pupils learn how to use the meters to which **they** have access by carrying out their own experiments.	Using a multimeter: http://www.doctronics.co.uk/meter.htm	
19(l)	State that *resistance = p.d./current* and use the equation *resistance = voltage/current* in calculations.		Ohm's Law: http://www.walter-fendt.de/ph11e/ohmslaw.htm	
19(m)	Describe an experiment to measure the resistance of a metallic conductor using a voltmeter and an ammeter and make the necessary calculations.	Perform the experiment for a metal/carbon conductor, plot V → I. Measure the gradient. State "This is a 50 V/A conductor" or whatever it is. Repeat with other values and plot on the same axes. "These are 20 V/A or 10 V/A conductors." This value tells us how hard it is to send a current through the conductor. The 50 V/A is offers more resistance than the 10 V/A. Resistance is measured in V/A – also called the ohm, Ω.	Current and voltage: http://jersey.uoregon.edu/vlab/Voltage/	

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19(q)	Describe the effect of temperature increase on the resistance of a resistor and a filament lamp and draw the respective sketch graphs of current/voltage.	Plot V → I for a tungsten filament bulb. Why is it not a straight line? Why is it harder to send a current through the filament when it is hot (temperature is not covered until unit 6 but pupils are likely to be aware of elementary kinetic theory)?	Temperature dependence of resistance: http://www.patana.ac.th/parents/curriculum/Physics_K4/units/DJFPh035.html	Use an ohmmeter to measure the resistance of a small low voltage bulb (e.g. 6V) heated up in a water bath or sprayed with a cooling spray. It requires a little time for the bulbs filament to reach any temperature outside.
19(n)	Discuss the temperature limitations on Ohm's Law.	When filament bulbs blow, why is it when they are switched on? The current surge occurs because the resistance is low when they are switched on.		
19(o)	Use quantitatively the proportionality between resistance and the length and the cross-sectional area of a wire.	Plot V → I for wires of different lengths and compare gradients. Or use an ohmmeter. Use a poor conductor with a significant resistance for a short length. Plot R → x. Repeat for different cross-sectional areas.	Dependence on length and area: http://www.regentsprep.org/Regents/physics/phys03/bresist/default.htm	Use conducting putty which can be extruded into cylinders of different cross-sectional areas and different lengths.
19(p)	Calculate the net effect of a number of resistors in series and parallel.	Plot V → I for parallel and series combinations. Emphasise: • "A thick wire is just many thin ones laid side by side" • "A long wire is just many short ones laid end to end"	Resistors in parallel and series: http://schools.matter.org.uk/Content/Resistors/Default.htm	Measure the resistance of networks made of *n* parallel branches of *n* resistors. How hot do the resistors get?
19(r)	Describe the operation of a light-dependent resistor.	Measure R at different light intensities for an L.D.R. It is difficult to measure the intensity easily or accurately but definite fractions of a standard intensity can be use by letting the light pass through a variable aperture, e.g. cut ever bigger holes in a piece of cardboard.	LDRs: http://www.doctronics.co.uk/ldr_sensors.htm or: http://www.antonine-education.co.uk/Physics_A2/Options/Module_9/Topic_6/TOPIC_6.HTM	
20(a)	Draw circuit diagrams with: power sources (cell, battery or a.c. mains),	These symbols are best learnt gradually in the course of describing experiments or when pupils write them up. It is not a good idea to produce a sheet containing all the	Circuit symbols: http://www.gcse.com/circuit_symbols.htm	Rectifying diodes do not feature largely elsewhere in this syllabus and it

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	switches (closed and open), resistors (fixed and variable), light dependent resistors, lamps, ammeters, voltmeters, magnetising coils, bells, fuses, relays, light emitting diodes, rectifying diodes.	symbols at the beginning of this section; this generates confusion. The teacher might, however, keep a record of the symbols encountered by the pupils as the course progresses and give out a full sheet when they have all been encountered separately.		might be sensible to investigate their conduction characteristics at this point.
20(c)	State that the sum of the potential differences in a series circuit is the equal to the potential difference across the whole circuit and use this in calculations.	Reminder: p.d. is concerned with where the energy ends up. Consider two resistors (AB and BC) in series. The energy which ends up between terminal A and C (i.e. in the two resistors) is equal to that which ends up between A and B added to that between B and C. Set up a series circuit and demonstrate this. Use the opportunity to include a section of circuit with resistors in parallel. Note these resistors all have the full p.d. of that section of the circuit across them which only counts once when finding the total p.d. across the circuit.	P.d.s in series: http://www.sec.org.za/physics/p10elpd.html	
20(e)	Do calculations on the whole circuit, recalling and using formulae including $R = V/I$ and those for potential differences in series, resistors in series and resistors in parallel.	Pupils will need to practise answering questions starting with simple circuits (one cell, one ammeter and one resistor) and gradually try more complicated arrangements as they become more proficient.	Resistance: http://hyperphysics.phy-astr.gsu.edu/hbase/electric/resis.html	