Unit 14

Answers: Electricity and Magnetism

Quick checks

1 **b** A line of force shows the way a positive test charge would be pushed. A positive charge is pulled toward a negative one, so the lines point inward. Circles would be wrong: electric lines of force start and end on charges, never going round in loops.

2 **b** Doubling both charges multiplies the force by $2 \times 2 = 4$; doubling the distance divides it by $2^2 = 4$. The two changes cancel, and the force is F again.

3 **b** Field intensity is force per unit charge, $E = F/q_0$: newtons divided by coulombs, N/C.

4 **b** The dielectric stops charge crossing between the plates, so the + and − charges stay apart and the capacitor stays charged. A good dielectric also increases the capacitance. Chemical reactions are how a cell works, not a capacitor.

5 **b** The prefix micro (μ) means one millionth, 10^{-6}. 10^{-9} F is a nanofarad and 10^{-12} F a picofarad.

6 **c** At a neutral point the magnet's field and the Earth's horizontal field cancel, so there is no field to turn the needle. It stays in whatever direction it was left. It doesn't spin: nothing pushes it.

7 **b** The magnet's field opposes the Earth's (points south) only to the sides of the magnet's middle, where its lines run from N back to S. On the axis, beyond the poles, its field points north, the same way as the Earth's, so there it can't cancel.

8 **b** The lines go into the Earth in the north, so the pole there attracts the N pole of a compass: it is a south pole. The magnetic axis is tilted about 10° from the axis of rotation, and the field is weakest at the magnetic equator, strongest near the poles.

9 **a** At the magnetic equator the Earth's field is horizontal, so a dip needle rests level: the angle of dip is 0°. It is 90° at the magnetic poles.

10 **c** Only in the magnetic meridian does the needle feel the whole of the field's horizontal part. In any other plane it feels the same vertical part but less of the horizontal part, so it dips more steeply than the true angle of dip, reaching 90° in the plane at right angles to the meridian.

11 **c** Nepal's declination in 2026 is between about 0.1° E at Biratnagar and 1.2° E at Darchula, in the far west. 44° is about the angle of dip, a different angle; 10° is about the tilt of the Earth's magnetic axis.

1 a. **a** A positive test charge is pushed directly away from a positive charge, so the lines point radially outward. Electric lines of force never form closed loops round a charge.

1 b. **c** $F \propto 1/r^2$: tripling r divides F by $3^2 = 9$.

1 c. **c** $k = 9 \times 10^9$ N m²/C². 6.67×10^{-11} is the gravitational constant G (in N m²/kg²), and 1.6×10^{-19} C is the charge of an electron.

1 d. **b** $F = \dfrac{9 \times 10^9 \times 2 \times 10^{-6} \times 3 \times 10^{-6}}{1^2} = 5.4 \times 10^{-2}$ N = 0.054 N. Both charges are positive, so they repel.

1 e. **b** A capacitor stores charge, as equal and opposite charges on two conductors separated by an insulator. Producing charge by chemical reactions is what a cell does.

1 f. **d** $Q = CV = 10\ \mu \times 6\ = 60\ \mu$. Microfarads times volts give microcoulombs.

1 g. **a** Outside the magnet the lines leave the N pole and enter the S pole; inside it they go from S to N, closing each loop.

1 h. **b** Beyond each end, on the axis, the magnet's field then points south, against the Earth's field, so the two cancel at a point on each side.

1 i. **b** It attracts the N pole of a compass, and unlike poles attract, so it is a south pole, though it is called the North Magnetic Pole for where it is.

1 j. **b** That is the definition of the angle of declination. The angle of dip (also called inclination) is the angle the field makes with the horizontal.

1 k. **c** A dip circle has a needle that turns in a vertical plane in front of a vertical scale. A declinometer measures the declination; a galvanometer measures small currents.

2 a. A test charge measures the field without changing it. A large charge would push or pull the charges making the field and move them, changing the very field it is meant to measure. It is positive by agreement, so that the direction of the force on it is the direction of the field.

2 b. The tangent to a line of force at a point gives the direction of the field there. If two lines crossed, there would be two tangents at the crossing, so the field would have two directions at the same point, which is impossible. So lines of force never intersect.

2 c. The force between charges in water is about 80 times weaker than in air, because the water molecules turn to face the ions and partly cancel their fields. So the attraction between the sodium and chloride ions becomes weak enough for the water molecules to pull them apart, and the salt dissolves.

2 d. The two plates of a capacitor are separated by an insulator, the dielectric, which charge can't cross. When a battery is connected, charge flows onto one plate and off the other for a short time, until the capacitor's voltage equals the battery's; then the flow stops. The charges stay on the plates, held by their attraction across the gap, so the capacitor stores charge, but no steady current flows.

2 e. These devices contain capacitors charged to high voltages, which can stay charged for a long time after the power is switched off. Touching their terminals would let them discharge through the body and give a dangerous shock.

2 f. The closeness of the lines shows the strength of the field. The field of a bar magnet is strongest at its poles, so the lines are crowded there and spread out farther away.

2 g. At a neutral point, the magnet's field is equal and opposite to the Earth's horizontal field, so the resultant field is zero. There is no force to turn the needle, so it stays in any direction it is left in.

2 h. The Earth behaves like a huge magnet whose S pole is near the geographic north. Unlike poles attract, so the N pole of the needle is pulled toward it, and the needle settles along the Earth's lines of force, pointing roughly north.

2 i. A dip needle settles along the Earth's field. At the magnetic equator the lines of force run parallel to the ground, so the needle rests horizontal (dip 0°). At the magnetic poles the lines go straight into or out of the ground, so the needle stands vertical (dip 90°).

2 j. In the magnetic meridian the needle feels the whole of the field's horizontal part and its vertical part, so it settles at the true angle of dip. In any other vertical plane it feels the same vertical part but only part of the horizontal part, so it dips more steeply; at right angles to the meridian it would stand straight up and down. So the true dip is read only in the magnetic meridian.

3 i.

Electric field	Electric field intensity
The region round a charge in which another charge feels a force.	The force on a unit positive charge at a point in the field.
A region of space; it has no value of its own.	A vector quantity with a value and a direction at each point.
Drawn with lines of force.	Calculated as $E = F/q_0$, or kQ/r^2 for a point charge.
No unit.	Unit: N/C.

3 ii.

Electric lines of force	Magnetic lines of force
Start on positive charges and end on negative charges.	Go from N to S outside a magnet and from S to N inside it.
Don't form closed loops.	Always form closed loops.
Show the direction of the force on a positive test charge.	Show the direction a compass's N pole points.
Leave or enter a conductor at right angles to its surface.	Pass through materials, entering and leaving a magnet.

3 iii.

Gravitational force	Electrostatic force
Acts between masses.	Acts between charges.
Always attractive.	Attractive between unlike charges, repulsive between like charges.
$F = Gm_1m_2/r^2$, G = 6.67×10^{-11} N m^2/kg^2.	$F = kq_1q_2/r^2$, k = 9×10^9 N m^2/C^2.
Very weak; not changed by what is between the bodies.	Very strong; weakened by an insulator between the charges.

3 iv.

Capacitor	Cell
Stores charge on two plates separated by an insulator.	Makes charge flow by chemical reactions.
Charges and discharges very quickly.	Charges (if rechargeable) and discharges slowly.
Its voltage falls steadily as it discharges.	Its voltage stays nearly steady until it is almost used up.
Stores little energy for its size.	Stores much more energy for its size.

3 v.

Geographic meridian	Magnetic meridian
The vertical plane through the place and the Earth's geographic North and South Poles.	The vertical plane through the place in which a freely suspended magnetic needle settles.
Its line on the ground points to true north.	Its line on the ground points to where a compass points.
Fixed for a place.	Changes slowly over the years.

3 vi.

Angle of declination	Angle of dip
The angle between the geographic meridian and the magnetic meridian.	The angle the Earth's magnetic field makes with the horizontal, in the magnetic meridian.
Measured in a horizontal plane.	Measured in a vertical plane.
Measured with a declinometer, or a compass and true north.	Measured with a dip circle.
About 0.4° E at Kathmandu (2026).	About 44° at Kathmandu (2026).

4 a. An electric field is the region round a charge in which another charge experiences an electrostatic force. The electric field intensity at a point is the force experienced by a unit positive charge placed at that point, $E = F/q_0$. Its SI unit is the newton per coulomb (N/C).

4 b. An electric line of force is the path along which a small, free positive charge would tend to move in an electric field; the tangent to it at any point gives the field's direction there. Properties:

1. They start on positive charges and end on negative charges.
2. They never cross each other.
3. They are close together where the field is strong and far apart where it is weak.
4. They leave or enter the surface of a conductor at right angles.

4 c. Draw a small circle for the charge with eight or more straight lines spreading from it evenly in all directions, like the spokes of a wheel.

i. For a positive charge, arrows on the lines point **away** from the charge.

ii. For a negative charge, the same lines with arrows pointing **toward** the charge. (Figure 14.2 shows both.)

4 d.

i. Lines leave the positive charge and curve round to enter the negative charge; the line through both is straight, and the others bulge outward.

ii. Lines leave both positive charges and bend away from each other; no line joins the two charges. The neutral point is at the midpoint between them, where the two fields are equal and opposite. (Figure 14.3 shows both.)

4 e. Coulomb's law: the force of attraction or repulsion between two point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them, and it acts along the line joining them.

$$F = \frac{kq_1q_2}{r^2}$$

In air (or a vacuum), k = 9×10^9 N m²/C².

4 f. One coulomb is the charge which, placed 1 m from an equal charge in air or a vacuum, repels it with a force of 9×10^9 N.

4 g.

i. The force doubles.

ii. The force becomes ½ × ½ = one fourth.

iii. The force becomes 2^2 = four times as large.

4 h. A capacitor is a device that stores electric charge, made of two conductors (plates) separated by an insulator (the dielectric). Its capacitance is the ratio of the charge on either plate to the potential difference between the plates, $C = Q/V$. The SI unit is the farad (F): one coulomb per volt.

4 i. A capacitor has a capacitance of one farad if a potential difference of one volt between its plates puts a charge of one coulomb on them. The farad is a very large unit: a capacitor of 1 F made of two plates 1 mm apart in air would need plates of about 113 km². Most real capacitors are millions or billions of times smaller, so their capacitances are written in μF (10^{-6} F), nF (10^{-9} F) or pF (10^{-12} F).

4 j. When the plates are connected to a battery, the battery pulls electrons off the plate joined to its positive terminal and pushes the same number onto the other plate; none cross the insulator. One plate becomes positive and the other equally negative. The flow slows as the charges build up and stops when the capacitor's voltage equals the battery's: it is charged. When its plates are then joined through a bulb or a wire, the extra electrons on the negative plate flow round to the positive plate, the bulb glows briefly, and the capacitor discharges.

4 k.

1. In a camera flash, to store charge and release it all at once into the flash tube.
2. In ceiling fans and water pumps, to help the motor start and run smoothly.
3. In phone chargers and power supplies, to smooth the bumpy direct current into a steady one.
4. In touchscreens, where a finger changes the capacitance at the point touched.

(Also: in radio tuning circuits, in computer memory, in defibrillators.)

4 l. A magnetic line of force is the path along which a free, isolated north pole would tend to move in a magnetic field; the tangent at any point gives the field's direction there. Properties:

1. Outside a magnet they go from N to S, and inside it from S to N, forming closed loops.
2. They never cross each other.
3. They are crowded where the field is strong (near the poles) and spread out where it is weak.
4. In a uniform field they are straight, parallel and evenly spaced.

4 m. Fix a sheet of paper on a table away from iron. Find the magnetic meridian with the compass and draw it; place the magnet along it and draw its outline, marking N and S. Place the compass near the N pole and mark the two ends of its needle with dots. Move the compass so that its S end is over the dot where its N end was, and mark the new position of the N end. Repeat until the S pole or the edge of the paper is reached. Join the dots with a smooth curve and mark its direction with an arrow from N to S. Repeat from other starting points near the N pole to draw several lines.

4 n. A neutral point is a point in a magnetic field where the field of a magnet is equal and opposite to the Earth's horizontal field, so the resultant field is zero; a compass there doesn't point in any particular direction.

i. With the N pole pointing north, the neutral points lie east and west of the magnet, on the line through its middle at right angles to it.

ii. With the N pole pointing south, they lie on the axis of the magnet, north and south, beyond its two ends. (Figure 14.8 shows both.)

4 o. The Earth's field is like that of a huge bar magnet placed at its center with its S pole toward the geographic north. Outside the Earth, the lines of force come out of the southern hemisphere and go into the northern hemisphere. The magnetic axis is tilted by about 10° from the Earth's axis of rotation, so the magnetic poles are not at the geographic poles. At the magnetic equator the lines run parallel to the ground; near the magnetic poles they are almost vertical. (Draw as in Figure 14.9: the Earth, the magnet inside with S toward the north, loops of lines from south to north, the geographic and magnetic axes, and the magnetic equator.)

4 p. The angle of declination at a place is the angle between the geographic meridian and the magnetic meridian. The angle of dip is the angle that the Earth's magnetic field makes with the horizontal, in the magnetic meridian (the angle by which a freely suspended needle dips below the horizontal there). At Kathmandu in 2026, the declination is about 0.4° E and the dip about 44°.

4 q.

1. The declination is used to turn a compass bearing into a true bearing, when using a compass with a map, or in ships and aircraft.
2. The angle of dip changes steadily from the magnetic equator to the poles, so it gives a rough idea of a place's latitude.
3. Changes in the dip and declination over a region help geologists find buried iron ore and study the rocks below.

4 r. Level the base of the dip circle with its leveling screws and spirit level. Turn the circle on the horizontal scale until the needle stands vertical: its plane is then at right angles to the magnetic meridian. Turn the circle through exactly 90°, so that the needle swings in the magnetic meridian. Read both ends of the needle on the vertical scale. Turn the circle through 180° and read both ends again. The mean of the readings is the angle of dip.

4 s. The dip at Pokhara is about 45°, so 70° is far too steep. A dip needle dips more steeply than the true angle whenever its plane is not in the magnetic meridian, so she has most likely not set the circle in the meridian. To check, she can turn the circle slowly on its horizontal scale: the reading is smallest in the magnetic meridian, and that smallest reading (about 45°) is the true dip. She could also check that a compass on the table points along the plane of the circle.

5 a.

$$E = \frac{kQ}{r^2} = \frac{9 \times 10^9 \times 8 \times 10^{-6}}{(0.20)^2} = \frac{7.2 \times 10^4}{0.04} = 1.8 \times 10^6$$

1.8×10^6 N/C, pointing away from the charge.

5 b.

$$E = \frac{F}{q} = \frac{0.02}{4 \times 10^{-6}} = 5000$$

For -10 μC: $F = qE = 10 \times 10^{-6} \times 5000 = 0.05$ N.
E = 5,000 N/C; the −10 μC charge feels 0.05 N, in the direction opposite to the field.

5 c.

$$F = \frac{9 \times 10^9 \times 5 \times 10^{-6} \times 4 \times 10^{-6}}{(0.30)^2} = \frac{0.18}{0.09} = 2$$

2 N, an attraction (unlike charges).

5 d.

$$q^2 = \frac{Fr^2}{k} = \frac{3.6 \times (0.05)^2}{9 \times 10^9} = \frac{9 \times 10^{-3}}{9 \times 10^9} = 10^{-12}\ ^2$$

q = 10^{-6} C = 1 μC each.

5 e.

$$r^2 = \frac{9 \times 10^9 \times 10^{-6} \times 10^{-6}}{0.1} = \frac{9 \times 10^{-3}}{0.1} = 0.09^{\,2}$$

r = 0.3 m = 30 cm.

5 f. Since $F \propto 1/r^2$, $F_1 r_1^2 = F_2 r_2^2$:

$$r_2 = r_1 \sqrt{\frac{F_1}{F_2}} = 6 \times \sqrt{\frac{16}{4}} = 6 \times 2 = 12$$

12 cm: a quarter of the force at twice the distance.

5 g.

$$F = \frac{9 \times 10^9 \times (10^{-7})^2}{(0.03)^2} = \frac{9 \times 10^{-5}}{9 \times 10^{-4}} = 0.1$$

Weight $= mg = 0.9 \times 10^{-3} \times 10 = 9 \times 10^{-3}$ N.
$F \div W = 0.1 \div 0.009 = 11$. **The electrostatic force is about 11 times the ball's weight**, though each ball carries only a tenth of a microcoulomb. This is why small charged bits of paper jump up to a comb against gravity.

5 h.

$$Q = CV = 220 \times 10^{-6} \times 9 = 1.98 \times 10^{-3}$$

About 1.98 mC.

5 i.

$$C = \frac{Q}{V} = \frac{0.6 \times 10^{-3}}{12} = 5 \times 10^{-5} \ = 50\ \mu$$

50 μF.

5 j.

i. $Q = CV = 150 \times 10^{-6} \times 300 = 0.045$ C.

ii. $I = \dfrac{Q}{t} = \dfrac{0.045}{1 \times 10^{-3}} = 45$ A.

0.045 C; an average current of 45 A, far more than the camera's small battery could give. The capacitor collects the charge slowly and lets it go all at once.

5 k.

$$Q = CV = 2.5 \times 10^{-6} \times 325 = 8.1 \times 10^{-4}$$

About 0.81 mC. (Nepal's mains is 230 V, but the voltage swings up and down 50 times a second, reaching about 325 V at each peak.)

5 l.

$$\tan\delta = \frac{V}{H} = \frac{30\sqrt{3}}{30} = \sqrt{3} \quad \Rightarrow \quad \delta = 60^\circ$$

The angle of dip is 60°. That is steeper than Kathmandu's 44°, so the place is nearer a magnetic pole than Kathmandu is. (A dip of about 60° is found in southern France.)