1)

(a)	(i)	**energy transferred from source/changed from some form to electrical energy**; per unit charge (to drive charge round a complete circuit)	**M1** A1	 allow energy divided by charge
	(ii)	any source has an internal resistance where energy is transferred into thermal energy /lost as heat	B1 B1	 there will be 'lost' volts (across the cell when a current is drawn) **or** $V = E - Ir$ explained
(b)	(i)	$V = IR$ $1.2 = 0.2\,R$ $R = 6.0\ \Omega$	C1 A1	substitution needed to score mark **allow** $6\ \Omega$
	(ii)	$1.6 - 1.2 = 0.4 = 0.2\,r$ $r = 2.0\ \Omega$	C1 A1	 **allow** $2\ \Omega$
(c)	(i)1	$Q = It = 0.20 \times 3600 \times 1.5$ =1100 correct unit,	C1 A1 B1	substitution needed to score mark 1080 **allow** 1 mark max for 0.3 or 18 **allow** C, kC, A s **exception** 0.3 A h or 18 A min scores 3 marks
	(i)2	energy = $QV = 1100 \times 1.2$ **or** $I^2Rt = 0.2^2 \times 6 \times 5400$ = 1320 (J)	C1 A1	**ecf (c)(i)1** substitution needed to score mark 1296(1080) **allow** 1 mark for 1728 (using 1.6)
	(ii)	I is constant for about 9 to 10 hours because internal resistance remains constant/cell operates at constant emf I falls rapidly/towards zero over last hour or so because cell's/chemical energy is used up (so E falls)	B1 B1 B1 B1	QWC must have link between observation and reason to score full marks **accept** r of cell increases causing fall in V or I
		Total	**17**	

2)

(a)	**(i)**	energy transferred from source/changed from some form to electrical energy; per unit charge (to drive charge round a complete circuit)	M1 A1	**allow** chemical
	(ii)	(some) energy is transferred into thermal energy /lost as heat in (driving charge through) the battery. It behaves as if it has an (internal) resistance/AW **or** there is a voltage drop across/decrease in voltage from the battery when a current is drawn from it/AW	B1	**allow** any description which uses $E = V + Ir$ with symbols defined but **not** just the formula alone **or** e.g. statement about 'lost volts'/current
(b)	**(i)**	correct substitution into resistors in parallel formula $R = 90\ \Omega$	C1 A1	$1/R = 1/90$ or 0.011 correct answer
	(ii)	using $V_{out} = R_2/(R_1 + R_2)\ V_{in}$: **alt:** $16 = I \times 120$ $V_{out} = 90/(30 + 90)\ 16$ so $I = 0.133$ A $V_{out} = 12$ V $V_{out} = 0.13 \times 90 = 12$ V	C1 C1 A1	**ecf (b)(i)** **accept** $V_{out} = (90/120) \times 16 = 12$ V for full marks **N.B.** beware of false ratios, e.g. 360/(120 + 360) giving correct answer; give first marking point only
	(iii)	resistance (of thermistor) decreases (with temperature increase) current in circuit increases **or** as total resistance is less so current in thermistor increases voltage ratio between 30 Ω and combination changes so voltage across thermistor falls	B1 M1 A1 M1 A1	**max** 4 marks QWC mark is either of the M marks
(c)	**(i)**	$Q = It = 1.2 \times 8 \times 60 \times 60$ $Q = 34560$ (C) correct unit,	C1 A1 B1	 **accept** 3.5 or 3.46×10^4 **allow** 1 mark for answer of 9.6 or 576 **allow** C, kC, A s; **N.B.** 9.6 A h or 576 A min score 3/3
	(ii)	energy = 34560 x 16 = 552960 J **or** I = 1.4/16 = 00875 A time = 552960/1.4 = 394970 s **then** t = 34560/I time = 394970/3600 = (109.7 h) = 110 h	C1 C1 A1	**ecf (c)(i)** **allow** full marks for 1.2 x 8 x 16/1.4 = 110 h **allow** 111 h when using 3.5×10^4 C
		Total	**18**	

3)

a	**i**	correct symbols (variable) R in series with ammeter and cell voltmeter correctly in parallel with variable R	B1 B1 B1	variable R and voltmeter needed **ecf** variable resistor symbol **accept** voltmeter in parallel with cell
	ii1	V decreases as I increases caused by R decreasing V is large when R is large **or** V is small when R is small V = e.m.f. when R is infinite/open circuit **or** V = 0 when R = 0 3.14 Ω at A; 0.88 Ω at B and 0.19 Ω at C any correct reference to internal resistance of cell	B1 B1 B1	**max 3 marks** with 2 marks for first two or second two marking points or three numbers and 1 mark for reference to r **allow** as R increases (decreases) V increases (decreases) for 1 mark but **not** as V increases R increases; **award 0/2** if reason given as V α R or I is constant
	ii2	at A I is small or V is much bigger than I/AW at C V is small or I is much bigger than V/AW product of V. and I is largest when the values of both quantities are about equal/half of the maximum value	B1 B1 B1	**accept** numerical answers, e.g. 0.39 W at A, 0.33 W at C 0.56 W at B for 2 marks comment on values for third mark
	ii3	1.4 (V)	B1	
	ii4	appreciating V against I is a straight line graph with gradient –r; giving r = 0.88 ± 0.02 Ω	C1 A1	**accept** using V = E – Ir **not** just quoting formula **allow** 0.8 ± 0.02 for calculation using any point on line N.B. can also have **ecf(ii)3**
b	**i**	intensity is the (incident) energy <u>per</u> unit area <u>per</u> second	B1	**accept** power per unit area or power per m^2 or (total) power/(surface) area
	ii	efficiency = power out/power in = 0.25/(800 x 2.5 x 10^{-3}) = 0.125 or 12.5%	C1 C1 A1	**not** energy out/energy in **accept** 13%
		Total question 3	**16**	

4)

a	**i**	12/2.0 = 6.0 (Ω)	B1	**allow** 6; do not apply the SF penalty (N.B. applied only once per paper) for any answer where the second SF is 0
	ii	attempt to <u>use</u> resistors in parallel formula 1/R = 8/6 R = 0.75 (Ω)	C1 C1 A1	no mark for just quoting formula **ecf (a)(i)** **allow** ¾ (Ω)
	iii	P = V^2/R = 12^2/0.75 **or** 8VI = 8 x 12 x 2 **or** I^2R = 16^2 x 0.75 = 192 W	C1 A1	**ecf (a)(ii)**
b		ρ = RA/l = 6.0 x 0.24 x 2.0 x 10^{-6}/0.9 = 3.2 x 10^{-6} Ω m	C1 C1 A1 B1	correct rearrangement of formula **ecf (a)(i);** substitution into a correct formula 2/3 marks for one or more POT errors **accept** 3.2 Ω μm; 4 x 10^{-7} scores 2/3
c	**i**	(As V is the same) then R must be the same to give <u>same P</u>	B1	**accept** alternative wording producing same argument, e.g. same I, same V so same R
	ii	0.75/8 = 0.094 (Ω)	B1	**ecf (a)(ii)**/8; **accept** 3/32 but NOT 0.09
	iii	for parallel circuit with break in one wire rest still work **or** series strips very wide (if use material of same resistivity as such low resistance/ giving poor visibility))	B1	any sensible statement
d	**i**	14 V	B1	
	ii	e.g. V = 12 V; I = 20 A substitution into E = V + Ir, e.g. 14 = 12 + 20 r r = 0.1 Ω	C1 C1 A1	**or** any suitable pair of readings from graph **ecf(d)(i); accept** r = gradient; = (14 – 10)/40 or similar ; = 0.1 Ω
		Total question 2	**17**	

5)

(a)	(i)	energy transfer per unit charge from chemical/other to electrical form	B1 B1	**allow** energy per unit charge
	(ii)	(Q = It =) 200 x 4 x 60 x 60 = 2.9 x 10^6 (C)	M1 A1	**accept** 200 x 14400 **accept** 2.88 x 10^6
	(iii)	E = QV = 2.88 x 10^6 x 24 = 6.9 x 10^7 (J)	C1 A1	 **accept** 72 MJ if using 3 MC or 69.6 or 70 if using 2.9 MC
(b)	(i)	correct symbol and polarity connected to X and Y	B1	**allow** one cell or more or two cells with dotted lines between
	(ii)	V = 30 – 24 = 6 V R = V/I = 6/120 = 0.05 (Ω)	M1 M1 A0	evidence of the V subtraction needed **do not allow** use of E = V + Ir; it must be I**R**
	(iii)	P = VI = 6 x 120 = 720 (J s^{-1})	C1 A1	**or** I^2R = 120^2 x 0.05 **or** V^2/R = 6^2 /0.05
	(iv)	(3600 – 720)/3600 = 2880/3600 = 0.8 = 80 (%)	C1 C1 A1	**ecf b(iii)**; using 2880 instead of 3600 gives 75%; scores zero **allow** (30 – 6)*I*/30*I* = 24/30 = 0.8 = 80 (%)
(c)	(i)	t = Q/I = 2.88 x 10^6/120 **or** E/VI = 69 x 10^6/(24 x 120) t = 2.4 x 10^4/3600 = 6.7 h	M1 A1	**ecf (a)(iii); accept** 3 x 10^6 giving 2.5 x 10^4 s and 6.9 h **allow ora** using 7.0 h giving E = 72.5 MJ
	(ii)	power supplied = 30 x 120/1000 = 3.6 kW cost = 3.6 x 7 x 26 = 655 (p)	 A1	**ecf c(i) accept** any consistent answer **do not allow** 2.88 kW giving 524 p **unless** repeated error from **b(iv)**
		Total	**17**	

6)

a		emf – J C^{-1}, resistance – V A^{-1}, energy – V C, charge – A s	**B1** **B1**	4 correct 2 marks; 2 correct 1 mark
b	**i**	energy per unit charge transferred from electrical to other forms	**B1** **B1**	**NOT** coulomb **allow** any other form e.g. heat, light, etc
	ii	(some) energy is transferred into thermal energy /lost as heat in (driving charge through) the battery. It behaves as if it has an (internal) resistance/AW **or** there is a voltage drop across/decrease in voltage from the battery (when a current is drawn from it)/AW	**B1**	**allow** any description which uses E = V + Ir but not just the formula alone, e.g. 'lost volts' per unit current is just accepable
	iii	p.d. across each branch is the same/branches in parallel resistance in X branch is 6 Ω, in YZ branch is 12 Ω so current in X branch is twice that in YZ branch/ as V = IR	**B1** **B1** **A0**	 **allow** R in X branch is half that in YZ branch/AW
	iv	V = IR = 0.08 x 6 V = 0.48 (V)	**C1** **A1**	
	v	the p.d. across each 3 Ω resistor is terminal p.d./2 **or** 0.48 V at Z there is 6 Ω either way to the supply/AW so p.d. across each 6 Ω is terminal p.d./2 so p.d. between X and Z is zero	**B1** **B1** **A0**	p.d./voltage across 3 Ω and 6 Ω are equal with justification
	vi	terminal p.d. = 0.96 V current in r = 0.16 + 0.08 = 0.24 A use of E = V + Ir 1.2 = 0.96 + 0.24 r giving r = 1.0 (Ω)	**C1** **C1** **C1** **A1**	**or** V = 0.24 x 4 **or** = 0.08 x 12 **or** 0.16 x 6 **or (iv)** x 2 **alt**: R in parallel gives 4.0 Ω; total R = 1.2/0.24 = 5.0 Ω r = 5.0 - 4.0 = 1.0 (Ω) **allow** 1SF
		Total	**15**	

7)

a	**i**	Q = It= 0.45 x 4.67 x 60 x 60 = 7600 C or As	C1 A1 B1	**accept** 7560 or 7570
	ii 1,2	**1** positive; **2** clockwise energy must be transferred to the cell **or** current in opposite direction transfers energy from the cell to the circuit/AW	M1 A1	positive plus correct direction of arrow for first mark; do not penalise if arrow not labelled I. **allow** (conventional) current is from positive to negative ; **or** electron flow from – to + [but current must be clockwise in **1**]
	3	V_{XY} = 1.5 + 0.45 x 0.90 V_{XY} = 1.9 (V)	C1 A1	 **accept** 1.905 or 1.91
	4	P = VI = 0.45 x 1.5 P = 0.675 (J s^{-1})	C1 A1	**allow** QV/t with **ecf a(i)** if necessary (11340/16800) **allow** 0.7 as final line if 0.675 appears above
b		**1.**cell across variable resistor R ammeter in series and voltmeter in parallel across R or cell **2.**Take (set of) readings of V and I for different positions/values of the variable resistor **3.**plot a graph of V against I **4.**(find) y-intercept = E **5.**(find) the gradient of the V against I graph which equals the internal resistance in magnitude **or 4 or 5** take one pair of values of V,I and substitute into equation E = V + Ir to find r or E	 B1 B1 B1 B1 B1	QWC last marking point needed for full marks **allow** use (digital) voltmeter across <u>unloaded</u> cell to find E; add R and find one value of V and I; then use equation to find r (points 2 to 5) **ignore** sign of gradient in determining r **allow** for no graph plot, using 2 pairs of values of V and I substituted into equation allows r and E to be found.(points 2 to 5)
c	**i**	4 x 1.5 V cells gives 6.0 V with r of 3.6 Ω so current is 6.0/(3.6 + 18) = 0.28 A requires (2 W/6 V =) 0.33 A to light normally or power delivered = (0.28^2 x 18 or 5.0 x 0.28)= 1.4 W **alt**: use 0.33 A & 6 V to show need emf of 7.2 V (1.8 V per cell)	B1 B1 B1	**allow** AW such as: 6 V but total R now 21.6 Ω; 6 V across 21.6 Ω gives 5 V across 18 Ω; requires 6 V to light normally **allow** P = 1.(6)7 W for 2 marks; only give the third mark if P labelled as power delivered by cell
	ii	1.5 n = 0.33 (18 + 0.9 n) **or** 1.5n = 6 + 0.3n so 3.6 n = 18 **or** 1.2n = 6 giving n = 5	M1 A1	**alt:** lamp needs V = 6V and I = 0.33 A terminal p.d per cell is 1.5 = V + 0.9 x 0.33 giving V = 1.2 V so n = 6/1.2 = 5 **allow** trial and error method but working must be shown to score any marks
		Total question 3	**19**	

8)

a		energy	A1	
b	**i**	energy (**available) to be** transferred from electrical to other forms **per unit charge** **or** energy transferred **across the terminals** from the supply **per unit charge**	B1 B1	**award** 1 mark for only one of the two bold phrases; 2 marks for both present **allow** 1 mark for answer which uses V = E - Ir with explanation **or** the p.d. across (the terminals of) the supply when it is delivering a current (to an external circuit)
	ii	The supply behaves as if it has an (internal) resistance causing (some) energy to be *transferred into thermal energy/lost as heat* **or** there is a *voltage drop across/decrease in voltage* from the supply when a current is drawn from it/AW	 B1	**NOT** the energy lost as heat inside the supply **allow** (causes) 'lost volts' per unit current (in the supply)
c	**i**	Take readings of V and I for several (five or more) positions/values of the variable resistor plot a graph of V against I the internal resistance is constant if the graph of V against I is a straight line <u>measure</u> the gradient of the V against I graph which equals the internal resistance **or** find y-intercept = E; find one pair of values of V,I substitute into equation E = V + Ir to find r	 B1 B1 B1 B1 B1	**Do not allow** any analysis with E assumed to be 6 V **allow** 2 pairs of values of V and I to be substituted into equation to find r (non-graph method max 2/5) **allow** <u>find</u> or similar word ignore problem of minus sign, i.e. assume value only
	ii	as a <u>safety/limiting</u> resistor **or** so the supply is not short-circuited (when variable resistor is reduced to zero)/AW	B1	**allow** e.g. to stop the current becoming too large/AW
d	**i**	arrow pointing clockwise	A1	arrow need not be on circuit wire
	ii	e.m.f = 4.5 – 2.4 (= 2.1 V) I = 2.1/(0.6 + 0.4 + 2.0) = 2.1/3.0 = 0.70 A	C1 A1	 **allow** 0.7 A
	iii 1	1.4 (V)	A1	**ecf(d)(ii)** i.e. answer = 2 x ans(d)(ii) **NOT** ecf when I = 1.05 A/3.45 A giving 2.1 V/6.9 V
	iii 2	V_x = 4.5 – 0.70 x 0.6 4.1 (V)	C1 A1	**ecf(d)(ii)**
		Total question 3	**16**	

9)

(a)		R's in parallel have same V/AW so 4.0 x 0.30 = 6.0 x 0.20	**M1** **A1**	**allow** I splits in inverse ratio to R **or** AW; hence I in 6 ohm = 4 / 6 x 0.3 = 0.2 A
(b)	(i)	sum of/total current into a junction equals the sum of/total current out **or** total algebraic sum of currents is zero	**B1**	**allow** Kirchhoff's first law
	(ii)	0.50 (A)	**A1**	**accept** 0.5 (A) (no SF error)
(c)		correct formula for R_p and substitution R_p = 2.4 Ω R_s = 8.0 (Ω)	**C1** **C1** **A1**	 **apply ecf** to R_p for second mark **accept** 8 (Ω) (no SF error)
(d)	(i)	energy transferred from source/changed from some form to electrical energy; per unit charge (to drive charge round a complete circuit)	**M1** **A1**	**allow** form as e.g. light/chemical/heat **allow** energy divided by charge
	(ii)	V = IR = 0.50 x 8.0 =4.0 (V)	**A1**	**ecf b(ii),c** i.e. answer = b(ii) x c **accept** 4 (V) (no SF error)
	(iii)	E – V = Ir giving 5.0 – 4.0 = 0.50 r r = 2.0 (Ω)	**C1** **A1**	**ecf b(ii)** **accept** 2 (Ω) (no SF error); give max of 1 mark for r = 3.3 Ω , i.e. using I = 0.3 A
		Total	**12**	

10)

(a)		E = I(R + r)	B1	
(b)	**(i) 1** **2**	0.80 Ω 6.4 V	B1 B1	
	(ii)	(sum of) e.m.f.s = sum /total of p.d.s/sum of voltages (in a loop)	B1	
	(iii)	6.4 = 0.80I I = 8.0 A	C1 A1	**can be 2 ecf** from **(b)(i),** eg 21.6/0.8 = 27 A (1 ecf) or 21.8/0.68 = 31.8 A (2 ecf)
(c)	**(i)**	Q = It = 2.5 x 6 x 60 x 60 = 54000 (C)	C1 A1	**allow** 1 mark if forgets one or two 60's giving 900 C or 15 C
	(ii)	energy = QE = 54000 x 14 = 756000 (J)	C1 A1	**allow** (use of 12 V gives) 648000 J for 1 mark
	(iii)	energy loss = I2Rt = VIt = 2 x 2.5 x 6.0 x 60 x 60= 108000 J percentage = (108000/756000) x 100 = 14%	C1 A1	**accept** QΔV = 54000 x 2.0 = 108000 J **accept** QΔV/QE = 2.0/14.0 = 14% **not** 756000/54000 = 14%
		Total question 2	**12**	

11)

Question			**Expected Answers**	**M**	**Additional Guidance**
	a	**i**	ions	B1	
		ii	positive ions	B1	**allow** positive charges / cations
		iii	electrons	B1	
	b	**i**	the battery has an internal resistance/AW some of the emf is across the (internal) resistance (leaving a smaller p.d. across motor)	B1 B1	**accept** connecting leads have resistance **accept** V = E - Ir or 'lost volts'/p.d. across r
		ii	use E = V + Ir giving 12 = 8 + 40r r = (12 – 8)/40 **or** 4/40 = 0.10 Ω	C1 M1 M1 A0	**accept** reverse solution, 0.10 Ω → 8 V→ 12 V substitution and or solution showing working
		iii	Q = It = 40 x 1.2 I= 48 (C)	C1 A1	
	c	**i**	The current heats the filament The resistance/resistivity (of the metal filament) increases (with temperature). .	B1 B1	no mention of temperature increase or heating scores zero
		ii	4.5 to 8 A in each (parallel) arm **or** 9 to 16 A for both together needs to be great enough to cover initial surge/current **or** use antisurge fuses	B1 B1	no mark if fuse value outside range
		iii	e.g. the starter motor draws 40 A so would need a bigger fuse than headlamp circuit so need different fuses for different situations **or** if battery used for starter motor with lights on will need too large a fuse – damage occurs before fuse blows/AW	B1	**accept** headlamp circuit damaged before fuse blows if 40 A fuse only used **or** fuse blows in starter circuit if 10 A used, etc.
			Total question 2	**15**	