Q1.

8 (a)	e.g. infinite (voltage) gain infinite input impedance zero output impedance infinite bandwidth infinite slew rate (*any three, 1 each*)	B3	[3]
(b) (i)	negative (feedback)	B1	[1]
(ii) 1	gain (= 5.8/0.069) = 84	B1	[1]
(ii) 2	gain = 1 + 120/X 84 = 1 + 120/X X = 1.45 kΩ	C1 A1	 [2]
(iii)	gain increases OR bandwidth reduced OR output increases	B1	[1]

Q2.

9 (a)	blocks labelled sensing device / sensor / transducer processor / processing unit / signal conditioning	B1 B1	 [2]
(b) (i)	two LEDs with opposite polarities *(ignore any series resistors)* correctly identified as red and green	M1 A1	 [2]
(ii)	correct polarity for diode to conduct identified hence red LED conducts when input (+)ve or *vice versa*	M1 A0	 [1]

Q3.

10 (a)	(part of) the output is added to /returned to / mixed with the input and is out of phase with the input / fed to inverting input	B1 B1	 [2]
(b)	25 = 1 + (120 / R) R = 5 kΩ	C1 A1	 [2]
(c) (i)	–2 V	A1	[1]
(ii)	9 V	A1	[1]

Q4.

9	(a)	(i)	point X shown correctly	B1	[1]
		(ii)	op-amp has <u>very large</u> / infinite gain	M1	
			non-inverting input is at earth (potential) / earthed / at 0 V	M1	
			if amplifier is not to saturate, inverting input must be (almost) at earth potential / 0 (V) same potential as inverting input	A1	[3]
	(b)	(i)	total input resistance = 1.2 kΩ	C1	
			(amplifier) gain (= –4.2 / 1.2) = –3.5	C1	
			(voltmeter) reading = -3.5×-1.5 = 5.25 V	A1	[3]
			(total disregard of signs or incorrect sign in answer, max 2 marks)		
		(ii)	(less bright so) resistance of LDR increases	M1	
			(amplifier) gain decreases	M1	
			(voltmeter) reading decreases	A1	[3]

Q5.

9	(a)	(i)	fraction of the output (signal) is added to the input (signal)	M1	
			out of phase by 180° / π rad / to inverting input	A1	[2]
		(ii)	e.g. reduces gain increases bandwidth greater stability reduces distortion (any two, 1 mark each)	B2	[2]
	(b)	(i)	gain = 4.4 / 0.062 = 71	A1	[1]
		(ii)	71 = 1 + 120/R	C1	
			R = 1.7×10^3 Ω	A1	[2]
	(c)		for the amplifier not to saturate	B1	
			maximum output is ($71 \times 95 \times 10^{-3}$ =) approximately 6.7 V	M1	
			supply should be +/– 9 V	A1	[3]

Q6.

10	(a)	(i)	strain gauge	B1	[1]
		(ii)	piezo-electric / quartz crystal / transducer	B1	[1]
	(b)	circuit:	coil of relay connected between sensing circuit output and earth	B1	
			switch across terminals of external circuit	B1	
			diode in series with coil with correct polarity for diode	B1	
			second diode with correct polarity	B1	[4]

Q7.

9	**(a)** to compare two potentials / voltages	M1	
	output depends upon which is greater	A1	[2]
	(b) (i) resistance of thermistor = 2.5 kΩ	C1	
	resistance of X = 2.5 kΩ	A1	[2]
	(ii) at 5 °C / at < 10 °C, $V^- > V^+$	M1	
	so V_{OUT} is –9 V	A1	
	at 20 °C / at > 10 °C, $V^- < V^+$ and V_{OUT} is +9 V	B1	
	V_{OUT} switches between negative and positive at 10 °C	B1	[4]
	(*allow similar scheme if 20 °C treated first*)		

Q8.

9	**(a)** <u>thin / fine</u> metal wire	B1	
	lay-out shown as a grid	B1	
	encased in plastic	B1	[3]
	(b) (i) gain (of amplifier)	B1	[1]
	(ii) for $V_{OUT} = 0$, then $V^+ = V^-$ *or* $V_1 = V_2$	C1	
	$V_1 = (1000/1125) \times 4.5$	C1	
	$V_1 = 4.0\,V$	A1	[3]
	(iii) $V_2 = (1000 / 1128) \times 4.5$		
	$= 3.99\,V$	C1	
	$V_{OUT} = 12 \times (3.99 - 4.00)$		
	$= (-)\ 0.12\,V$	A1	[2]

Q9.

10	**(a)** light-dependent resistor (allow LDR)	B1	[1]
	(b) (i) two resistors in series between +5 V line and earth	M1	
	midpoint connected to inverting input of op-amp	A1	[2]
	(ii) relay coil between diode and earth	M1	
	switch between lamp and earth	A1	[2]
	(c) (i) switch on/off mains supply using a low voltage/current output	B1	[1]
	(allow 'isolates circuit from mains supply')		
	(ii) relay will switch on for one polarity of output (voltage)	C1	
	switches on when output (voltage) is negative	A1	[2]

Q10.

9 **(a)** e.g. infinite input impedance/resistance zero output impedance/resistance infinite (open loop) gain infinite bandwidth infinite slew rate (*any four, one mark each*)		B4	[4]
(b) graph: square wave		M1	
180° phase change		A1	
amplitude 5.0 V		A1	[3]
(c) correct symbol for LED		M1	
diodes connected correctly between V_{OUT} and earth		A1	
diodes identified correctly		A1	[3]
(*special case: if diode symbol, not LED symbol, allow 2nd and 3rd marks to be scored*)			

Q11.

9 **(a)** **(i)** light-dependent resistor/LDR	B1	[1]
(ii) strain gauge	B1	[1]
(iii) quartz/piezo-electric crystal	B1	[1]
(b) **(i)** resistance of thermistor decreases as temperature increses	M1	
etiher $V_{OUT} = V \times R / (R + R_T)$		
or current increases <u>and</u> $V_{OUT} = IR$	A1	
V_{OUT} increases	A1	[3]
(ii) *either* change in R_T with temperature is non-linear		
or V_{OUT} is not proportional to R_T/ change in V_{OUT} with R_T is non-linear	M1	
so change is non-linear	A1	[2]

Q12.

9 **(a)** 30 litres → 54 litres *(allow ± 4 litres on both limits)*	A1	[1]
(b) **(i)** only 0.1 V change in reading for 10 litre consumption *(or similar numbers)*	B1	
above about 60 litres gradient is small compared to the gradient at about 40 litres	B1	[2]
(ii) voltmeter reading (nearly) zero when fuel is left	C1	
voltmeter reads only about 0.1 V when 10 litres of fuel left in tank	A1	[2]
("voltmeter reads zero when about 4 litres of fuel left in tank" scores 2 marks)		

Q13.

8 (a) (i) - 9 V

(ii) + 9 V (*both **(i)** and **(ii)** correct for the mark*) .... B1 [1]

(b) ✕ ✕ B1
✓ ✕ B1
✓ ✓ .... B1 [3]
(*no e.c.f. from **(a)***)

(c) (i) cct: thermistor and resistor in series M1
output connections across thermistor .... A1 [2]

(ii) as temperature decreases, thermistor resistance increases B1
p.d. across thermistor $= R_T / (R + R_T) \times V$ M1
as R_T increases, output increases .... A1 [3]

Q14.

10 (a) (i) 1. inverting (amplifier)	B1	[1]
2. gain of op-amp is very large / infinite	B1	
non-inverting input is at earth / 0V	B1	
for amplifier not to saturate, P must be at about earth / 0V	B1	[3]
(ii) input resistance is very large	B1	
(so) current in R_1 = current in R_2	B1	
$I = V_{IN} / R_1$	B1	
$I = -V_{OUT} / R_2$ (*minus sign can be in either of the equations*)	B1	
hence *gain* $= V_{OUT} / V_{IN} = -R_2 / R_1$	A0	[4]
(b) (i) 1. feedback resistance = 33.3 kΩ	C1	
gain (= 33.3 / 5) = 6.66	C1	
V_{OUT} (= 6.66 × 1.2) = 8.0 V (*+ or – acceptable, allow 1 s.f.*)	A1	[3]
2. feedback resistance = 8.33 kΩ	C1	
V_{OUT} (= {6.66 × 1.2} / 5) = 2.0 V (*+ or – acceptable, allow 1 s.f.*)	A1	[2]
(ii) (Increase in lamp-LDR distance gives) decrease in intensity	M1	
Feedback / LDR resistance increases	M1	
voltmeter reading increases / becomes more negative	A1	[3]

Q15.

9 (a) resistance of wire $= \rho L / A$ B1
as crack widens, *L* increases M1
and *A* decreases M1
so resistance increases .... A0 [3]

(b) $\Delta L / L = \Delta R / R$ B1
$= (146.2 - 143.0) / 143.0 \times 100$ C1
$\Delta L / L = 2.24\%$ .... A1 [3]

[Total: 6]

Q16.

10 at 16 °C, $V^+ = 1.00$ V and $V^- = 0.98$ V *or* $V^+ > V^-$ B1
at 16 °C, output is positive M1
diode R is 'on' <u>and</u> diode G is 'off' A1
as temperature rises, diode R goes 'off' <u>and</u> diode G goes 'on' .... B1 [4]
(*allow e.c.f. from 2nd to 3rd marks and also 3rd to 4th marks*)

[Total: 4]

Q17.

9 **(a)** e.g. reduces gain
increases bandwidth
less distortion
greater stability ....(*1 each, max 2*) .... B2 [2]

(b) gain $= -R_F / R_I$
$= -8.0 / 4.0$ M1
numerical value is 2 .... A0 [1]

(c) **(i)** 2, 6 and 7 .... A1 [1]

(ii) e.g. digital-to-analogue converter (*allow DAC*)
adding / mixing signals with 'weighting' .... B1 [1]

[Total: 5]

Q18.

9 **(a)** **(i)** non-inverting (amplifier) B1 [1]

(ii) $(G =)\ 1 + R_2 / R_1$ B1 [1]

(b) **(i)** gain = 1 + 100 / 820 C1
output = 17 mV A1 [2]

(ii) 9 V A1 [1]
(R_2 / R_1 scores 0 in **(a)(ii)** but possible 1 mark in each of **(b)(i)** and **(b)(ii)**
$(1 + R_1 / R_2)$ scores 0 in **(a)(ii)**, no mark in **(b)(i)**, possible 1 mark in **(b)(ii)**
$(1 - R_2 / R_1)$ or R_1 / R_2 scores 0 in **(a)(ii)**, **(b)(i)** and **(b)(ii)**)

Q19.

10 **(a)** e.g. infinite input impedance / resistance zero output impedance / resistance infinite gain infinite bandwidth infinite slew rate (*any three, 1 each*)	B3	[3]
(b) **(i)** with switch open, V^- is less (positive) than V^+	M1	
output is positive	A1	
with switch closed, V^- is more (positive) than V^+ so output is negative (*allow similar scheme if V^- more positive than V^+ treated first*)	A1	[3]
(ii) **1.** diodes connected correctly between output and earth	M1	
2. green identified correctly (*do not allow this mark if not argued in **(i)***)	A1	[2]

Q20.

9 **(a)** e.g. reduced gain increased stability greater bandwidth or less distortion *(allow any two sensible suggestions, 1 each, max 2)*	B2	[2]
(b) **(i)** V^- connected to midpoint between resistors	B1	
V_{OUT} clear and input to V^+ clear	B1	[2]
(ii) gain = $1 + R_F/R$ 15 = $1 + 12000/R$	C1	
R = 860 Ω	A1	[2]
(c) graph: straight line from (0,0) to (0.6,9.0)	B1	
straight line from (0.6,9.0) to (1.0,9.0)	B1	[2]
(d) *either* relay can be used to switch a large current/voltage	M1	
output current of op-amp is a few mA/very small	A1	[2]
or relay can be used as a remote switch	(M1)	
for inhospitable region/avoids using long heavy cables	(A1)	

Q21.

9 **(a)** any value greater than, or equal to, 5 kΩ	B1	[1]
(b) **(i)** 'positive' shown in correct position	B1	[1]
(ii) V^+ = (500/2200) × 4.5 ≈ 1 V	B1	
$V^- > V^+$ so output is negative	M1	
green LED on, (red LED off) *(allow full ecf of incorrect value of V^+)*	A1	[3]
(iii) *either* V^+ increases *or* $V^+ > V^-$	M1	
green LED off, red LED on	A1	[2]

Q22.

9	(a)	e.g. zero output impedance/resistance infinite input impedance/resistance infinite (open loop) gain infinite bandwidth infinite slew rate *1 each, max. 3*	B3	[3]
	(b) (i)	graph: square wave correct cross-over points where $V_2 = V_1$ amplitude 5 V correct polarity (*positive at t = 0*)	M1 A1 A1 A1	[4]
	(ii)	correct symbol for LED diodes connected correctly between V_{OUT} and earth correct polarity consistent with graph in **(i)** (*R points 'down' if **(i)** correct*)	M1 A1 A1	[3]

Q23.

9	(a)	light-emitting diode (*allow LED*)	B1	[1]
	(b)	gives a high or a low output / +5 V or –5 V output dependent on which of the inputs is at a higher potential	M1 A1	[2]
	(c) (i)	provides a reference/constant potential	B1	[1]
	(ii)	determines temperature of 'switch-over'	B1	[1]
	(d) (i)	relay	A1	[1]
	(ii)	relay connected correctly for op-amp output and high-voltage circuit diode with correct polarity in output from op-amp	B1 B1	[2]

Q24.

9	(a)	operates on / takes signal from sensing device (so that) it gives an voltage output	B1 B1	[2]
	(b)	thermistor and resistor in series between +4 V line and earth V_{OUT} shown clearly across *either* thermistor *or* resistor V_{OUT} shown clearly across thermistor	M1 A1 A1	[3]
	(c)	e.g. remote switching switching large current by means of a small current isolating circuit from high voltage switching high voltage by means of a small voltage/current (*any two sensible suggestions, 1 each to max. 2*)	B2	[2]

Q25.

9 **(a)**	e.g. zero output impedance/resistance infinite input impedance/resistance infinite (open loop) gain infinite bandwidth infinite slew rate (*1 each, max. 3*)	B3	[3]
(b) **(i)**	gain = 1 + (10.8 / 1.2) = 10	C1 A1	[2]
(ii)	graph: straight line from (0,0) towards V_{IN} = 1.0 V, V_{OUT} = 10 V horizontal line at V_{OUT} = 9.0 V to V_{IN} = 2.0 V correct +9.0 V → –9.0 V (and correct shape to V_{IN} = 0)	B1 B1 B1	[3]

Q26.

11 **(a)** **(i)**	inverting amplifier	B1	[1]
(ii)	gain is <u>very</u> large/infinite V^+ is earthed/zero for amplifier not to saturate, P must be (almost) earth/zero	B1 B1 B1	[3]
(b) **(i)**	R_A = 100 kΩ R_B = 10 kΩ V_{IN} = 1000 mV	A1 A1 A1	[3]
(ii)	variable range meter	B1	[1]

Q27.

10 **(a)**	compares the potentials/voltages at the (inverting and non-inverting) <u>inputs</u>	B1	
	either output (potential) dependent on which input is the larger *or* $V^+ > V^-$, then V_{OUT} is positive states the other condition	B1 B1	[3]
(b) **(i)**	ring drawn around both the LEDs (and series resistors)	B1	[1]
(ii)	V^- = (1.5 × 2.4)/(1.2 + 2.4) = 1.0 V (*allow* 1.5 × 2.4/3.6 = 1.0 V)	B1	[1]
(iii) **1.**	V_{OUT} switches at +1.0 V maximum V_{OUT} is 5.0 V when curve is above +1.0 V, V_{OUT} is negative (*or v.v.*)	B1 B1 B1	[3]
2.	at time t_1, diode R is emitting light, diode G is not emitting at time t_2, diode R is not emitting, diode G is emitting (*must be consistent with graph line. If no graph line then 0/2*)	B1 B1	[2]

Q28.

10	(a)		e.g. zero output resistance / impedance infinite bandwidth infinite slew rate *1 mark each, max. 3*	B3	[3]
	(b)	(i)	at 1.0 °C, thermistor resistance is 3.7 kΩ amplifier gain = $-R/740$ = –3700 / 740 *(negative sign essential)* = –5.0	B1 C1 C1	
			potential = 1.0 / –5.0 = –0.20 V	A1	[4]
		(ii)	at 15 °C, R = 2.15 kΩ (*allow ±0.05 kΩ*) reading = (2150 / 740) × 0.2 = 0.58 V (0.59 V → 0.57 V)	C1 A1	[2]
	(c)	(i)	0.68 V	A1	[1]
		(ii)	resistance (of thermistor) does not change linearly with temperature	B1	[1]

Q29.

10	(a)	(i)	thermistor / thermocouple	B1	[1]
		(ii)	quartz crystal / piezoelectric crystal *or* transducer / microphone	B1	[1]
	(b)	(i)	V_{OUT} = –5 V inverting input is positive *or* V_- is positive *or* $V_- > V_+$ so V_{OUT} is negative op-amp has very large / infinite gain and so saturates	A1 B1 B1	[3]
		(ii)	sketch: V_{OUT} switches from (+) to (–) when V_{IN} is zero V_{OUT} is +5 V or –5 V V_{OUT} is negative when V_{IN} is positive (*or v.v.*)	B1 M1 A1	[3]