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) \[ \text{gain} = \frac{5.8}{0.069} = 84 \]  B1 [1]
    (ii) \[ \text{gain} = 1 + \frac{120}{X} \]
    \[ X = \frac{1.45 \text{ k}\Omega}{1 + \frac{120}{X}} \]  C1
    (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) \[ 25 = 1 + \frac{120}{R} \]
    \[ R = 5 \text{ k}\Omega \]  C1  A1 [2]

(c) (i) \(-2\) V  A1 [1]
    (ii) 9 V  A1 [1]

Q4.
Q5.

9 (a) (i) point X shown correctly B1 [1]
   (ii) op-amp has very large / infinite gain
        non-inverting input is at earth (potential) / earthed / at 0 V
        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
       (amplifier) gain = \(-4.2 / 1.2\) = \(-3.5\)
       (voltmeter) reading = \(-3.5 \times -1.5\) = 5.25 V
       (total disregard of signs or incorrect sign in answer, max 2 marks) C1

   (ii) (less bright so) resistance of LDR increases
        (amplifier) gain decreases
        (voltmeter) reading decreases M1

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
    switch across terminals of external circuit
    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
output depends upon which is greater

(b) (i) resistance of thermistor = 2.5 kΩ
resistance of X = 2.5 kΩ

(ii) at 5 °C at < 10 °C, V<sup>-</sup> > V<sup>+</sup>
so V<sub>OUT</sub> is -9 V
at 20 °C at > 10 °C, V<sup>-</sup> < V<sup>+</sup> and V<sub>OUT</sub> is +9 V
V<sub>OUT</sub> switches between negative and positive at 10 °C
(allow similar scheme if 20 °C treated first)

Q8.

9 (a) thin / fine metal wire
lay-out shown as a grid
encased in plastic

(b) (i) gain (of amplifier)

(ii) for V<sub>OUT</sub> = 0, then V<sup>+</sup> = V<sup>-</sup> or V<sub>i</sub> = V<sub>2</sub>
V<sub>i</sub> = (1000/1125) × 4.5
V<sub>i</sub> = 4.0 V

(iii) V<sub>2</sub> = (1000 / 1128) × 4.5
     = 3.99 V
V<sub>OUT</sub> = 12 × (3.99 - 4.00)
     = (-) 0.12 V

Q9.

10 (a) light-dependent resistor (allow LDR)

(b) (i) two resistors in series between +5 V line and earth
midpoint connected to inverting input of op-amp

(ii) relay coil between diode and earth
switch between lamp and earth

(c) (i) switch on/off mains supply using a low voltage/current output
(allow isolates circuit from mains supply)

(ii) relay will switch on for one polarity of output (voltage)
switches on when output (voltage) is negative

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
180° phase change
amplitude 5.0 V
M1 A1 A1 [3]

(c) correct symbol for LED
diodes connected correctly between V_{OUT} and earth
A1 A1 [3]
diodes identified correctly
(special case: if diode symbol, not LED symbol, allow 2^{nd} and 3^{rd} 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 increases M1
\[ V_{OUT} = V \times \frac{R}{(R + R_T)} \]
or current increases and \[ V_{OUT} = IR \]
\[ V_{OUT} \] increases A1 A1 [3]

(ii) either change in \( R_T \) with temperature is non-linear M1
or \( V_{OUT} \) is not proportional to \( R_T \) change in \( V_{OUT} \) with \( R_T \) 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.
Q14.

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

(b) \[ \times \times \] .................................................. B1 [3]
   (no 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 = \( R_t \times \frac{V}{R+R_t} \) ................................... M1
   as \( R_t \) increases, output increases ........................................... A1 [3]

Q15.

10 (a) (i) 1. inverting (amplifier) .................................................... B1 [1]
   2. gain of op-amp is very large / infinite
      non-inverting input is at earth / 0 V
      for amplifier not to saturate, \( P \) must be at about earth / 0 V .... B1 [3]
   (ii) input resistance is very large
      (so) current in \( R_t \) = current in \( R_2 \)
      \[ I = \frac{V_{IN}}{R_1} \] ............................................... B1
      \[ I = -\frac{V_{OUT}}{R_2} \] (minus sign can be in either of the equations) .... B1
      hence gain = \( \frac{V_{OUT}}{V_{IN}} = -\frac{R_2}{R_1} \) ........................................ A0 [4]

(b) (i) 1. feedback resistance = 33.3 kΩ ......................................... C1
      gain (= \( \frac{33.3}{5} \) ) = 6.66 ......................................... C1
      \[ V_{OUT} = (6.66 \times 1.2) = 8.0 \text{ V} \] (+ or - acceptable, allow 1 s.f.) A1 [3]
   2. feedback resistance = 8.32 kΩ .............................................. C1
      \[ V_{OUT} = (6.66 \times 1.2) / 5 \approx 2.0 \text{ V} \] (+ or - acceptable, allow 1 s.f.) A1 [2]
   (ii) (Increase in lamp LDR distance gives) decrease in intensity
      Feedback / LDR: resistance increases
      voltmeter reading increases / becomes more negative ................ M1

Q16.

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

[Total: 6]
Q17.

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

(b) gain = \(-R_2 / R_1\)
= \(-8.0 / 4.0\) ..................................................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 = \(1 + 100 / 820\)
output = 17 mV ..................................................C1

(ii) 9V
\((R_2 / R_1\) 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)(iii), (b)(i) and (b)(iii)

Q19.
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
$V_{OUT}$ clear and input to $V^+$ clear B1 [2]

(ii) gain = $1 + R_d/R$
$15 = 1 + 12000/R$
$R = 860 \Omega$ C1 A1 [2]

(c) graph: straight line from (0,0) to (0,6.9,0)
straight line from (0,6.9,0) to (10,9,0) B1 [2]

(d) either relay can be used to switch a large current/voltage
output current of op-amp is a few mA/very small M1 A1 [2]
or relay can be used as a remote switch
for inhospitable region/avoids using long heavy cables (M1) (A1)

Q21.

9 (a) any value greater than, or equal to, 5k\Omega B1 [1]

(b) (i) ‘positive’ shown in correct position B1 [1]

(ii) $V^+ = (500/2200) \times 4.5$
$= 1 V$
$V^- > V^+$ so output is negative B1 [2]
green LED on, (red LED off)
(allow full ec of incorrect value of $V^+$) M1 A1 [3]

(iii) either $V^+$ increases or $V^+ > V^-$
green LED off, red LED on M1 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

(b) (i) graph: square wave
  correct cross-over points where $V_2 = V_1$
  amplitude 5V
  correct polarity (positive at t = 0)
  M1
  A1
  A1
  [4]

(iii) 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)

(b) gives a high or a low output / $+5\, \text{V}$ or $-5\, \text{V}$ 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 $+4\, \text{V}$ 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.
Q26.

11 (a) (i) inverting amplifier
(ii) 
- gain is very large/infinite
- $V^+$ is earthed/zero
- for amplifier not to saturate, $P$ must be (almost) earth/zero

(b) (i) $R_a = 100 \, k\Omega$
- $R_b = 10 \, k\Omega$
- $V_{\text{in}} = 1000 \, \text{mV}$
(ii) variable range meter

Q27.

10 (a) compares the potentials/voltages at the inverting and non-inverting inputs

- either: output (potential) dependant on which input is the larger
- or: $V^+ > V^-$, then $V_{\text{out}}$ is positive

(b) (i) ring drawn around both the LEDs (and series resistors)
(ii) $V = (1.5 \times 2.4)/(1.2 + 2.4) = 1.0 \text{ V}$
- (allow $1.5 \times 2.4/3.6 = 1.0 \text{ V}$)
(iii) 1. $V_{\text{out}}$ switches at $+1.0 \text{ V}$
- maximum $V_{\text{out}}$ is $5.0 \text{ V}$
- when curve is above $+1.0 \text{ V}$, $V_{\text{out}}$ is negative (or v.v.)
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 $0/2$)
10 (a) e.g. zero output resistance/impedance
infinite bandwidth
infinite slew rate
1 mark each, max. 3

(b) (i) at 1.0°C, thermistor resistance is 3.7 kΩ
amplifier gain = \(-R/740 = -3700/740\) (negative sign essential)
\(= -5.0\)
potential = 1.0/-5.0 = -0.20 V

(ii) at 15°C, \(R = 2.15 \text{ kΩ} \) (allow ±0.05 kΩ)
reading = \((2150/740) \times 0.2\)
\(= 0.58 \text{ V} \) (0.59 V → 0.57 V)

(c) (i) 0.68 V

(ii) resistance (of thermistor) does not change linearly with temperature

Q29.

10 (a) (i) thermistor/thermocouple

(ii) quartz crystal/piezoelectric crystal or transducer/microphone

(b) (i) \(V_{\text{OUT}} = -5 \text{ V}\)
inverting input is positive or \(V_\text{in} \) is positive or \(V > V_\text{in} \) so \(V_{\text{OUT}} \) is negative
op-amp has very large/infinite gain and so saturates

(ii) sketch: \(V_{\text{OUT}} \) switches from (+) to (–) when \(V_{\text{IN}} \) is zero
\(V_{\text{OUT}} \) is +5 V or -5 V
\(V_{\text{OUT}} \) is negative when \(V_{\text{IN}} \) is positive (or v.v.)