Unit 3

Area of study 2: Electronics and photonics

Chapter 4

Electronics

1. (i) (a) $\frac{1}{R_{eff}} = \frac{1}{30} + \frac{1}{20}$

$= \frac{5}{60}$

$= \frac{1}{12}$

$R_{eff} = 12\ \Omega$

$R_{eff} = R_1 + R_2$

$= 12 + 12$

$= 24\ \Omega$

(b) $R_{eff} = 6 + 12$

$= 18\ \Omega$

(c) $\frac{1}{R_{eff}} = \frac{1}{30 + 10} + \frac{1}{40}$

$= \frac{2}{40}$

$= \frac{1}{20}$

$R_{eff} = 20\ \Omega$

(d) $R_{eff} = 5 + 12 + 3$

$= 20\ \Omega$

(ii) (a) $I = \frac{V}{R}$

$= \frac{12}{24}$

$= 0.50$ A

(b) $I = \frac{V}{R}$

$= \frac{9}{18}$

$= 0.50$ A

(c) $I = \frac{V}{R}$

$= \frac{5}{20}$

$= 0.25$ A

(d) $I = \frac{V}{R}$

$= \frac{60}{20}$

$= 3$ A

(iii) (a)

12 Ω	30 Ω	20 Ω
$V = IR$	$V = 12 - 6$	$V = 12 - 6$
$= 0.5 \times 12$	$= 6.0$ V	$= 6.0$ V
$= 6.0$ V		

(b)

6 Ω	20 Ω	30 Ω
$V = IR$	$V = 9 - 3$	$V = 9 - 3$
$= 0.5 \times 6$	$= 6.0$ V	$= 6.0$ V
$= 3.0$ V		

(c)

10 Ω	30 Ω	40 Ω
$V = \frac{10}{30 + 10} \times 5$	$V = \frac{30}{30 + 10} \times 5$	$V = 5.0$ V
$= \frac{5}{4}$	$= \frac{15}{4}$	
$= 1.3$ V	$= 3.7$ V	

(d)

3 Ω	10 Ω
$V = IR$	$V = IR$
$= 3 \times 3$	$= 3 \times 5$
$= 9.0$ V	$= 15$ V

20 Ω	30 Ω
$V = 60 - 15 - 9$	$V = 36$ V
$= 36$ V	

(iv) (a)

12 Ω	20 Ω	30 Ω
0.50 A	$I = \frac{V}{R}$	$I = \frac{V}{R}$
	$= \frac{6}{20}$	$= \frac{6}{30}$
	$= 0.30$ A	$= 0.20$ A

(b)

6 Ω	20 Ω	30 Ω
0.50 A	$I = \frac{V}{R}$	$I = \frac{V}{R}$
	$= \frac{6}{20}$	$= \frac{6}{30}$
	$= 0.30$ A	$= 0.20$ A

(c)

10 Ω	30 Ω	40 Ω
$I = 0.13$ A	$I = 0.13$ A	$I = \frac{V}{R}$
		$= \frac{5}{40}$
		$= 0.13$ A

(d)

3 Ω	10 Ω	20 Ω	30 Ω
$I = \frac{V}{R}$	$I = \frac{V}{R}$	$I = \frac{V}{R}$	$I = \frac{V}{R}$
$= \frac{9}{3}$	$= \frac{15}{10}$	$= \frac{36}{20}$	$= \frac{36}{30}$
$= 3.0$ A	$= 1.5$ A	$= 1.8$ A	$= 1.2$ A

2. (a) $V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$

$= \frac{2.2}{2.2 + 2.2} \times 6.0$

$= 3.0$ V

(b) $$\frac{1}{R_{\text{eff}}} = \frac{1}{4.4} + \frac{1}{4.4} = \frac{2}{4.4} = \frac{1}{2.2}$$

$R_{\text{eff}} = 2.2\ \text{k}\Omega$

so $V_{\text{out}} = 3.0\ \text{V}$

3. $$\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{2.0}{6.0} = \frac{1}{3}$$

so $$\frac{R_2}{R_1 + R_2} = \frac{1}{3}$$

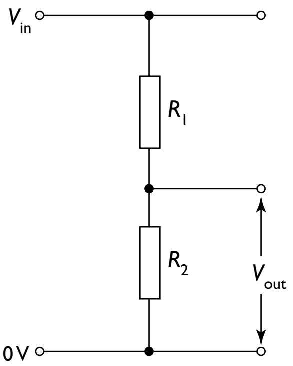
$$\Rightarrow \frac{R_2}{3.0 + R_2} = \frac{1}{3}$$

$\Rightarrow 3R_2 = 3.0 + R_2$

$2R_2 = 3.0$

$$R_2 = \frac{3.0}{2} = 1.5\ \text{k}\Omega$$

4. (a)



$$V_{\text{out}} = \frac{R_2 V_{\text{in}}}{R_1 + R_2}$$

$V_{\text{in}} = 10\ \text{V}$

$R_1 = 60\ \Omega$

$R_2 = 40\ \Omega$

$$V_{\text{out}} = \frac{40\ \Omega \times 10\ \text{V}}{(60\ \Omega + 40\ \Omega)} = 4.0\ \text{V}$$

(b) $$V_{\text{out}} = \frac{R_2 V_{\text{in}}}{R_1 + R_2 + R_3}$$

$V_{\text{in}} = 9\ \text{V}$

$R_1 = 20\ \Omega$

$R_2 = 30\ \Omega$

$R_3 = 40\ \Omega$

$$\Rightarrow V_{\text{out}} = \frac{30\ \Omega \times 9\ \text{V}}{90\ \Omega} = 3.0\ \text{V}$$

(c) $$V_{\text{out}} = \frac{4R \times 20\ \text{V}}{R + 4R} = \left(\frac{4R}{5R}\right) 20\ \text{V} = 0.8 \times 20\ \text{V} = 16\ \text{V}$$

5. As the resistance decreases, so, too, does the voltage drop across the variable resistor.

6. (a) $$V_{\text{out}} = \frac{R_2 V_{\text{in}}}{R_1 + R_2}$$

$V_{\text{out}} = 4.0\ \text{V}$

$V_{\text{in}} = 6.0\ \text{V}$

$R_1 = 3.0\ \text{k}\Omega$

$R_2 = R$

$$\Rightarrow 4.0\ \text{V} = \frac{R\ \text{k}\Omega \times 6.0\ \text{V}}{(3.0 + R)\ \text{k}\Omega}$$

$\Rightarrow 12 + 4R = 6R$

$\Rightarrow 2R = 12$

$\Rightarrow R = 6$

$R = 6.0\ \text{k}\Omega$

(b) $$V_{\text{out}} = \frac{R_2 V_{\text{in}}}{R_1 + R_2}$$

$$\Rightarrow 6.0 = \frac{12R}{R + 660}$$

$\Rightarrow 6R + 6 \times 660 = 12R$

$\Rightarrow 6R + 3960 = 12R$

$\Rightarrow 6R = 3960$

$\Rightarrow R = 660\ \Omega$

(c) $$V_{\text{out}} = \frac{R_2 V_{\text{in}}}{R_1 + R_2}$$

$$\Rightarrow 2.5 = \frac{10R}{10 + R}$$

$\Rightarrow 25 + 2.5R = 10R$

$\Rightarrow 7.5R = 25$

$\Rightarrow R = 3.3\ \text{k}\Omega$

(d) $$V_{\text{out}} = \frac{R_2 V_{\text{in}}}{R_1 + R_2}$$

$$\Rightarrow 6 = \frac{5 \times 9}{R + 5}$$

$\Rightarrow 6R + 30 = 45$

$\Rightarrow 6R = 15$

$\Rightarrow R = 2.5\ \text{k}\Omega$

7. (a) Output voltage divided by input voltage
   (b) Gradient of linear section of the transfer characteristic

8. The output voltage of an inverting amplifier *increases* as the input voltage decreases, as long as the input voltage is in the linear range.

9. Characteristic (a)
   (i) gain = gradient of linear section of graph
   $$= \frac{5 - 1}{1 - (-1)} = \frac{4}{2} = 2$$
   (ii) Maximum output voltage = 5.0 V (from graph)
   Minimum output voltage = 1.0 V (from graph)
   (iii) Non-inverting (positive gradient in linear section)

   Characteristic (b)
   (i) $$\text{gain} = \frac{0.5 - 5.5}{[3.0 - (-3.0)] \times 10^{-3}} = \frac{-5.0}{6.0 \times 10^{-3}}$$
   = 830 (take positive value for gain)
   (ii) Maximum output voltage = 5.5 V
   Minimum output voltage = 0.5 V

(iii) Inverting (negative gradient)

Characteristic (c)

(i) $\dfrac{1-5}{(4-1)\times 10^{-3}} = \dfrac{-4}{3\times 10^{-3}}$

$= 1.3\times 10^{3}$

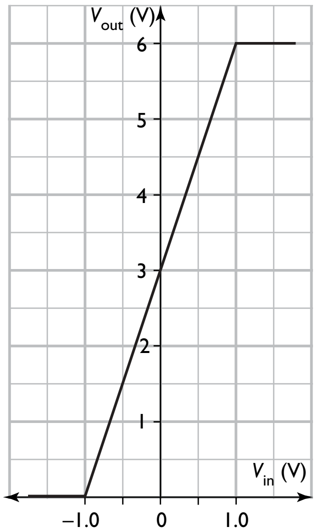
(take positive value for gain)

(ii) Maximum output voltage = 5.0 V

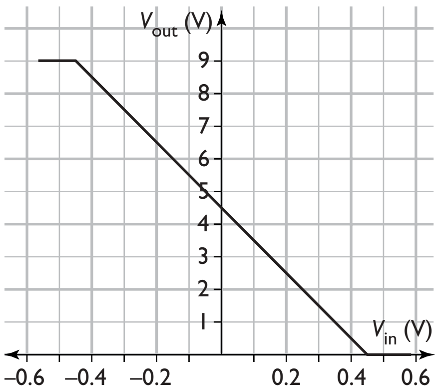
Minimum output voltage = 1.0 V

(iii) Inverting (negative gradient)

10. (a)



(b)



11. (a) (i) $R = 5.0$ kΩ (by reading graph)

(ii) $R = 1.0$ kΩ (by reading graph)

(b) (i) 25°C (by reading graph)

(ii) 50°C (by reading graph)

12. (a) If the temperature is 40°C, $R_2 = 2$ kΩ

$R_1 = 4$ kΩ

$V_{out} = \dfrac{R_2 V_{in}}{R_1 + R_2}$

$= \dfrac{2\times 9\text{ V}}{4+2}$

$= 3.0$ V

(b) If the temperature is 80°C, $R_2 = 1$ kΩ.

$R_1 = ?$

$V_{in} = 9$ V

$V_{out} = 6.0$ V

$\Rightarrow 6.0\text{ V} = \dfrac{1\times 9\text{ V}}{R_1 + 1}$

$\Rightarrow 6R_1 + 6 = 9$

$\Rightarrow 6R_1 = 3$

$\Rightarrow R_1 = 0.5$ kΩ

$= 500$ Ω

13. (a) Positive — the resistance increases with temperature.

(b) 70°C from graph

(c) 8.0 kΩ from graph

(d) T = 90°C

$R_{thermistor} = 8.0$ kΩ (from (c))

$\dfrac{V_{out}}{V_{in}} = \dfrac{R_{thermistor}}{R_{variable} + R_{thermistor}}$

$\dfrac{3}{9} = \dfrac{8.0}{R_{var} + 8.0}$

$3R_{var} + 24 = 72$

$3R_{var} = 48$

$R_{var} = 16$ Ω

(e) The output voltage drops. This is because the proportion of the resistance in the circuit taken by the resistor decreases, so the voltage drop decreases.

14. (a) 5000 Ω (from graph)

(b) 200°C (from graph)

(c) T = 200°C, $R_{thermistor} = 400$ Ω (from (b))

$V_{out} = \dfrac{R_{thermistor}}{R_{thermistor} + R_{variable}} \times V_{in}$

$\Rightarrow \dfrac{V_{out}}{V_{in}}(R_{thermistor} + R_{variable}) = R_{thermistor}$

$\Rightarrow \dfrac{V_{out}}{V_{in}} R_{variable} = R_{thermistor}\left(1 - \dfrac{V_{out}}{V_{in}}\right)$

$R_{variable} = R_{thermistor}\left(\dfrac{V_{in}}{V_{out}} - 1\right)$

$= 400\left(\dfrac{12}{8} - 1\right)$

$= 200$ Ω

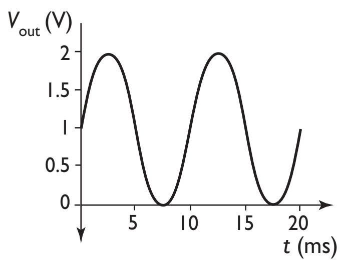
15. (a) Gain $= \dfrac{\Delta V_{out}}{\Delta V_{in}}$

$= \dfrac{8}{0.4}$

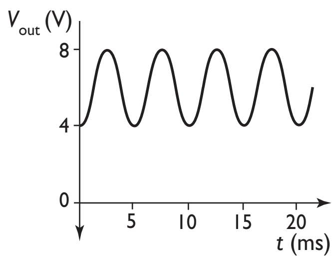
$= 20$

(b) Non-inverting. An increase in V_{in} leads to an increase in V_{out}.

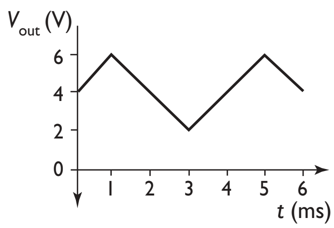
(c) (i)



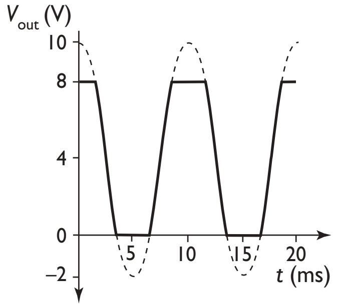
(ii)



(iii)



(iv)

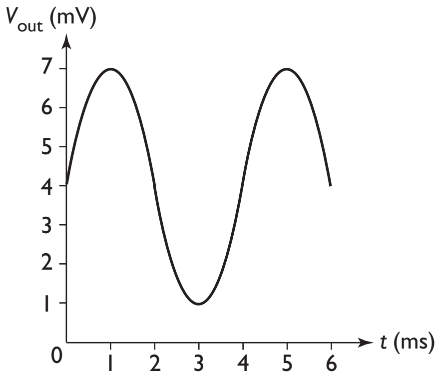


16. (a) Gain equals the (absolute value of the) gradient of the transfer characteristic in the linear section.

$$A_v = \frac{\Delta V_{out}}{\Delta V_{in}}$$
$$= \frac{1 - 7\ (\text{V})}{(40 - 10) \times 10^{-3}\ (\text{V})}$$
$$= \frac{-6}{3.0 \times 10^{-2}}$$
$$= -200$$
$$= 200 \text{ (take absolute value)}$$

(b) This amplifier is inverting because an increase in the input voltage produces a decrease in the output voltage.

(c)



(d) 10 mV to 40 mV (values read from graph)

17. (a) 0.7 V (midpoint of linear region of characteristic)

(b) 5.0 V (midpoint of linear region of characteristic)

(c) Treat R_1 and R_2 as a voltage divider. R_1 = 10 kΩ, V_{in} = 10 V (from characteristic)

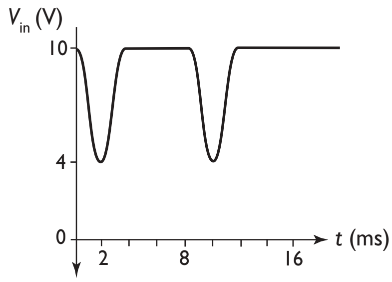
$V_{out} = V_{in}$ of the amplifier
= 0.7 V for correct biasing.

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$
$$\frac{V_{out}}{V_{in}}(R_1 + R_2) = R_2$$
$$\frac{V_{out}}{V_{in}} R_1 = R_2 \left(1 - \frac{V_{out}}{V_{in}}\right)$$
$$R_2 = \frac{\frac{V_{out}}{V_{in}} R_1}{1 - \frac{V_{out}}{V_{in}}}$$
$$= \frac{R_1}{\frac{V_{in}}{V_{out}} - 1}$$
$$= \frac{10\,000}{\frac{10}{0.7} - 1}$$
$$= 7.5 \times 10^2\ \Omega$$

(d) 2.0 V (from characteristic)

(e) 10.0 V (from characteristic)

(f)



(g) Capacitor C_1 prevents any DC component of the signal voltage affecting the bias of the amplifier. C_2 removes the bias component of the output voltage and protects the amplifier from any voltage that V_{out} is connected to. C_e prevents AC currents in R_e from affecting the base current.

18. (a) Read value from graph.
Answer is approximately 0.65 V.
Accept 0.6 V to 0.7 V.

(b) $V_R = E - V_D$
$= 6.0\ \text{V} - 0.65\ \text{V}$
$= 5.35\ \text{V}$

(c) $V_R = IR$
$I = 4.0 \times 10^{-3}$ A

$$R = \frac{V}{I}$$
$$= \frac{5.35\ \text{V}}{4.0 \times 10^{-3}}$$
$$= 1337.5\ \Omega$$
$$= 1.3 \times 10^3\ \Omega \text{ or } 1.3\ \text{k}\Omega$$

(d) −6.0 V as the diode is now reverse biased

(e) $I = 0$

(f) $V_R = 0$

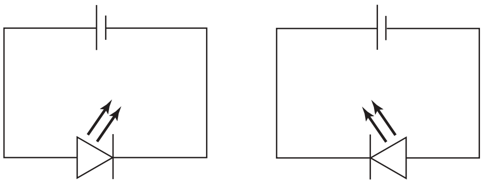
19. The distortion is due to clipping. The flat batteries reduce the maximum value for V_{out}. In Jasper's case the maximum value has fallen below the value produced by the amplification of a strong radio signal.

Chapter 5

Introductory photonics

1. A transducer is a device that transforms energy from one form to another.
2. The resistance (in an LDR) is a function of the intensity of light shining on the LDR — the more light, the less resistance.
3. Some cameras contain light meters that use voltage dividers containing an LDR. The intensity of the light affects the resistance of the LDR, which changes the voltage to the light meter.
4. (a) LEDs are semiconductor diodes designed to emit light when they conduct a current. They contain a semiconductor chip with p-type material connected to the anode by a fine wire and n-type material connected to the cathode through contact with a metal base.

(b) A diode is forward biased when the p-type material — the anode — is connected to a higher voltage than the cathode. In this situation, current will flow if the voltage difference is greater than a minimum value, which is determined by the nature of the semiconducting material and, hence, the colour. A diode is reverse biased, and blocks the flow of current if the anode is connected to a lower voltage than the cathode.



Forward biased   Reverse biased

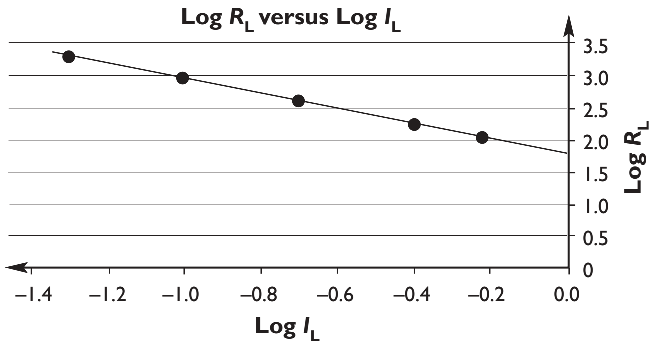
5. Indicator lights on electronic equipment — they need to last for the life of the equipment, be compact and energy efficient
   Some clock and cash register displays for the same reasons
   Stop lights in cars
6. LEDs emit light according to the choice of impurities in the semiconductor. All diodes emit some light but the choice of impurities and the structure of the diode maximise the light produced.
7. Limiting resistors are needed because a forward-biased diode has a very low resistance. This can result in a current large enough to destroy the diode.
8. A photodetector converts light signals into electrical signals.
9. (a) A photodiode is one that is sensitive to light. It can be used to measure light intensity. If reverse biased, a photodiode begins to conduct when light shines on it. Alternatively, it can be used as a source of electric current when light shines on it.
   (b) Phototransistors operate like photodiodes but they amplify the collector–base current, making them more sensitive than photodiodes.
   (c) Photodiodes have a faster response time.
   (d) Phototransistors are more sensitive.
   (e) Photodiodes respond more quickly than phototransistors, increasing the bandwidth of photonic systems that use them instead of phototransistors.
10. (a) Phototransistors have a base current that is proportional to the intensity of the light incident on it, so the collector current is also proportional to the intensity of the light. In a normal transistor, the base current is produced by a voltage divider and a signal from an external device. Phototransistors usually do not have a base terminal as transistors do.
    (b) The base current in a phototransistor is produced by light shining on the collector–base junction giving sufficient energy for some electrons in the depletion region to escape their atoms and form a small current.
11. (a) Bandwidth is the amount of data that can be transmitted in a fixed amount of time.
    (b) 15 000 Hz — the system bandwidth is equal to the maximum frequency it can carry
    (c) Optical fibres can carry up to 1 terabps (= 1×10^{16} binary digits per second).
    Telephone wires can carry up to 100 Mbps (= 1×10^{8} binary digits per second).
    Optical fibre can carry $\dfrac{10^{16}}{10^{8}} = 10^{8}$ times as much data per second as metal wire.
    (d) Metal wires have a higher density of charge carriers (free electrons) near the surface when carrying an alternating current. This makes the resistance of the wire greater for alternating current than direct current, causing loss of signal power.
    (e) The skin effect is the result of electromagnetic effects.
12. (a) Optical intensity modulation occurs when the intensity of a light source is affected by the varying electrical signal from a transducer.
    (b) The signal from a microphone is a current of changing magnitude. This signal can be used to modulate the light emitted from a suitably biased LED.
13. (a) 0.4 lux (from graph)
    (b) $V_{out} = \dfrac{R_2}{R_1 + R_2} V_{in}$

$$= \frac{3000}{3000 + 2000} \times 6$$
$$= \tfrac{3}{5} \times 6$$
$$= 3.6 \text{ V}$$

    (c) As illumination increases, the resistance of the LDR decreases, resulting in an increase in V_{out}.
14. (a)

Relative light intensity I_L	LDR Current (μA)	LDR Voltage (V)	LDR Resistance (kΩ)	Log R_L	Log I_L
0.6	350	38.7	111	2.04	–0.22
0.4	220	39.0	177	2.25	–0.40
0.2	90	39.1	434	2.64	–0.70
0.1	40	39.0	975	2.99	–1.00
0.05	20	39.0	1950	3.29	–1.30

    (b)



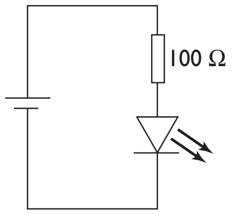
    (c) $\log R_L = 1.17 \log I_L + 1.80$
$$R_L = I_L^{1.17} \times 10^{1.80}$$
$$R_L = 63\ I_L^{1.17}$$
    (d) An LDR is not ohmic because $\dfrac{V}{I}$ is not constant.
15. (a) (i) 1.6 V (from graph)
    (ii) $V_R = 6.0 - 1.6$
    $= 4.4$ V
    (iii) $R = \dfrac{V}{I}$
$$= \frac{4.4}{0.02}$$
$$= 220\ \Omega$$
    (b) (i) 6.0 V (reverse-biased diode with 6.0 V supply)
    (ii) 0 A
    (iii) 0 V ($V = IR$)

16. (a) 1.7 V (or 1.8 V) (from graph)
(b) $V = IR$
$= 0.06 \times 500$
$= 30$ V
(c) emf = 30 + 1.7 (or 30 + 1.8)
= 31.7 V (or 31.8 V)

17. (a) The diode is reverse biased and therefore non-conducting.
(b) 2.5 V — the voltage must drop across the diode as the voltage across the resistor is given by $V = IR$ (= 0).

18. (a) $V = 9.0 - 1.8$
$= 7.2$ V
(b) $R = \frac{V}{I}$
$= \frac{7.2}{0.04}$
$= 180\ \Omega$

19. (a) $V_R = 9.0 - 1.7$
$= 7.3$ V
$R = \frac{V_R}{I}$
$= \frac{7.3}{0.02}$
$= 365\ \Omega$
$= 3.7 \times 10^2\ \Omega$
(b) $V_R = 12 - 1.7$
$= 10.3$ V
$R = \frac{V_R}{I}$
$= \frac{10.3}{0.02}$
$= 515\ \Omega$
$= 5.2 \times 10^2\ \Omega$
(c) $V_R = 24 - 1.7$
$= 22.3$ V
$R = \frac{V_R}{I}$
$= \frac{22.3}{0.02}$
$= 1115$
$= 1.1\ \mathrm{k}\ \Omega$
(d) $V_R = 50 - 1.7$
$= 48.3$ V
$R = \frac{V}{I}$
$= \frac{48.3}{0.02}$
$= 2415$
$= 2.4 \times 10^3\ \Omega$

20. (a)


Resistor has 15 − 2 = 13 V across it.
$I = \frac{V}{R} = \frac{13}{100} = 0.13$ A
(b) The LED might burn out because the current is too high.