Answers to Exercises in Chapter 16

16.1 The electrical properties of conductors, insulators and semiconductors are described in Section 16.2.

16.2 Silicon, germanium and gallium arsenide are used (amongst others). The most widely used material is silicon.

16.3 Electrons are negative charge carriers and will move *against* an applied electric field generating an electrical current. Holes, being the absence of an electron, act like positive charge carriers and will move *in the direction* of an applied electric field and will also contribute to current flow.

16.4 These terms are discussed in Section 16.3.

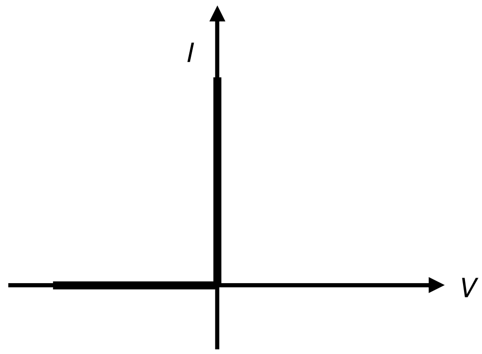
16.5 Intrinsic conduction refers to the conduction that takes place due to the thermally generated charge carriers within pure semiconductors. Extrinsic conduction takes place as a result of the charge carriers produced by doping a semiconductor. Conduction within doped semiconductors is dominated by that due to a flow of *majority* charge carriers.

16.6 The 'depletion layer' refers to the region close to a *pn* junction that has very few mobile charge carriers. The reasons why this results in a potential barrier are discussed in Section 16.4.

16.7 Diode action and the effects of an external voltage on the drift and diffusion currents are discussed in Section 16.4.

16.8 The current-voltage characteristics of a silicon diode are shown in Figure 16.10.

16.9 A diode is an electrical component that conducts electricity in one direction but not the other. The characteristics of an ideal diode are as follows:



16.10 They are effectively the same thing, except that the term rectifier tends to be used for components that are being used to convert alternating waveforms into unidirectional waveforms (as within a power supply).

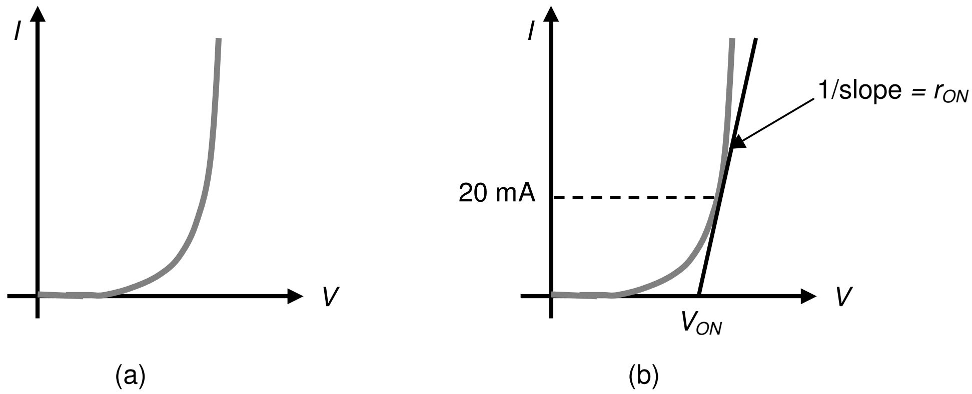
16.11 The reverse saturation current is the approximately constant current that flows in a reverse-biased diode.

16.12 The 'turn-on' voltage of a diode is the forward bias voltage at which (when viewed on a large scale) the device appears to start conducting. The 'conduction voltage' of a diode is the approximately constant voltage across the conducting diode. For a silicon diode the turn-on voltage is about 0.5 V and the conduction voltage is about 0.7 V.

16.13 Germanium diodes have a turn-on voltage of about 0.2 V and a conduction voltage of about 0.25 V. Gallium arsenide diodes have a turn-on voltage of about 1.3 V and a conduction voltage of about 1.4 V.

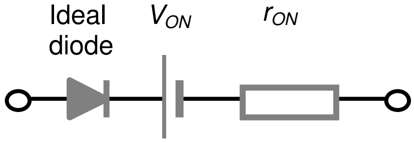
16.14 The use of diode equivalent circuits of different levels of sophistication is discussed in Section 16.6.2.

16.15 First the *I/V* characteristic of the diode is plotted using an appropriate simulation package, as shown in (a) below.



A tangent to the characteristic is now drawn such that this touches the line at the current to be used in the circuit. The slope of this line can be used to determine the effective resistance of the diode at this current, and the intersection between the line and the horizontal axis gives the effective ON voltage of the diode. (b) above shows this for a typical diode current of 20 mA.

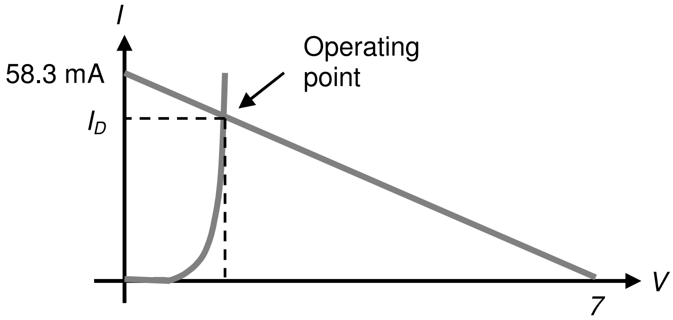
A suitable equivalent circuit would then be



For a 1N4002, typical values for V_{ON} and r_{ON} might be 0.68 V and 2.7 Ω.

16.16 For a 1N914, typical values for V_{ON} and r_{ON} might be 0.95 V and 2.1 Ω.

16.17 The circuit may be analysed as described in Section 16.6.3. Here the supply voltage is 7V, and E/R is equal to 7/120 = 58.3 mA. Therefore we can construct a load-line of the form shown below. The values obtained will depend on the diode used.



16.18 If the diode can be adequately represented by an ideal diode and a fixed voltage source, the diode characteristic in the above load-line can be replaced by a vertical line at the V_{ON} of the diode, simplifying the determination of I_D. However, in this case a load-line is not really necessary (as discussed in Section 16.6.3) since the current will be given by $I = (V - V_{ON})/R = (7 - V_{ON})/120$. For a typical value of V_{ON} of 0.7 V, this gives $I = (7 - 0.7)/120 = 52.5$ mA.

16.19 Zener breakdown and avalanche breakdown are discussed in Section 16.6.5.

16.20 Increasing R reduces power dissipation within the regulator. However, the maximum value of R is determined by the minimum input voltage and the maximum output current, since

$V - IR \geq 5.6$ V

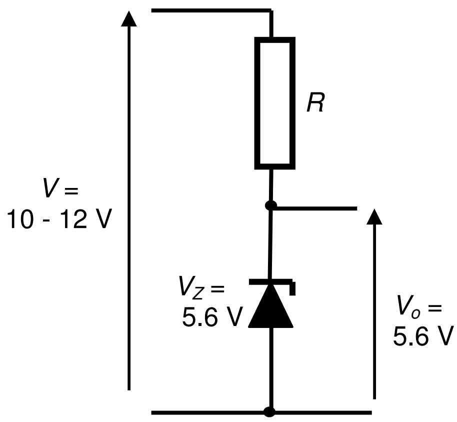
Thus when $V = 10$ V and $I = 100$ mA

$10 - 0.1R \geq 5.6$

so

$R \leq 44\ \Omega$

Therefore choose $R = 44\ \Omega$.



Maximum power dissipation in the diode occurs when the input voltage is at a maximum (12 V) and no current is taken by the load. Under these circumstances the voltage across the R is 12 – 5.6 = 6.4 V, so the current through R (and hence through the diode) is 6.4/44 = 145 mA. The power dissipation in the diode is this current multiplied by the voltage across the diode (5.6 V) so P_{max} = 815 mW.

16.21 The current is constant at 100 mA, and the capacitance is 220 μF, so

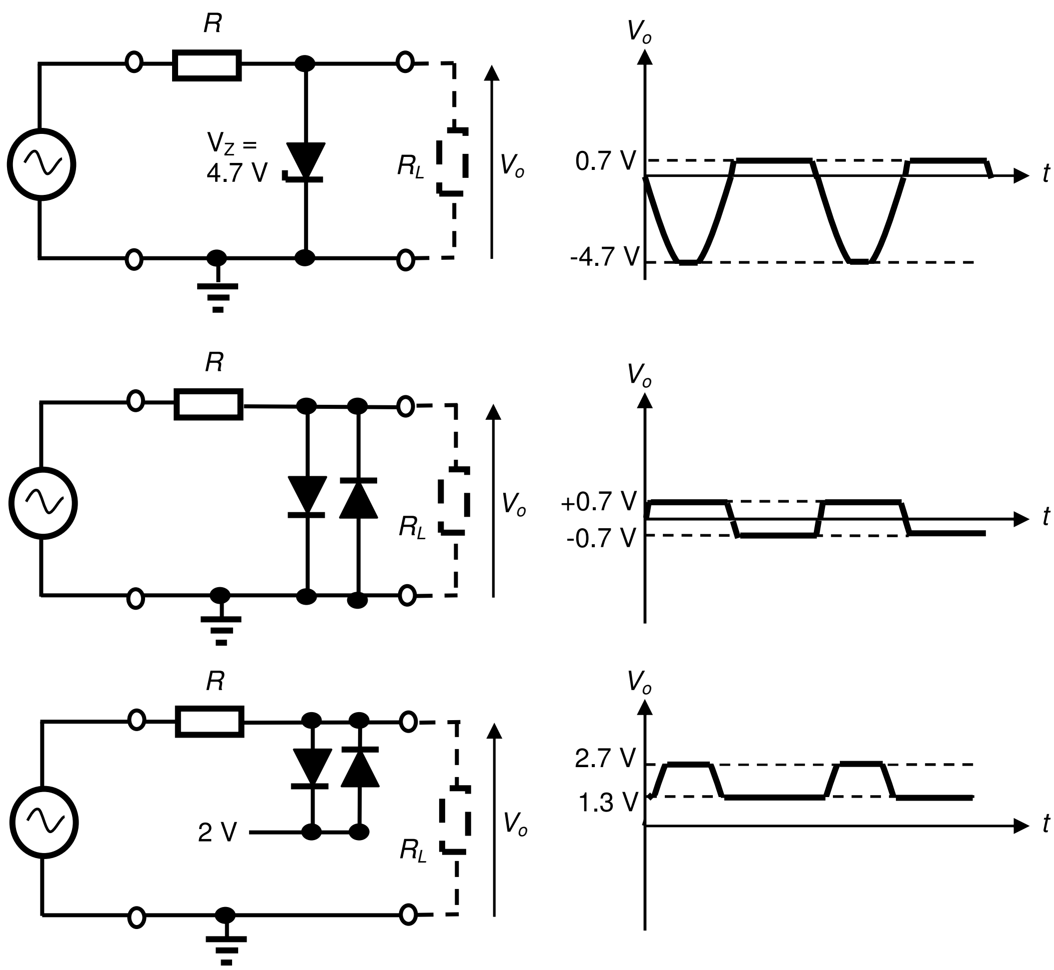
$$\frac{dV}{dt} = \frac{i}{C} = \frac{0.1}{220 \times 10^{-6}} = 455 \text{ V/s}$$

Therefore the output voltage will fall at a rate of 455 volts per second.

During each cycle the capacitor is discharged for a time almost equal to the period of the input, which is 20 ms. Therefore, during this time the voltage on the capacitor (the output voltage) will fall by 20 ms × 455 V/s = 9.1 volts.

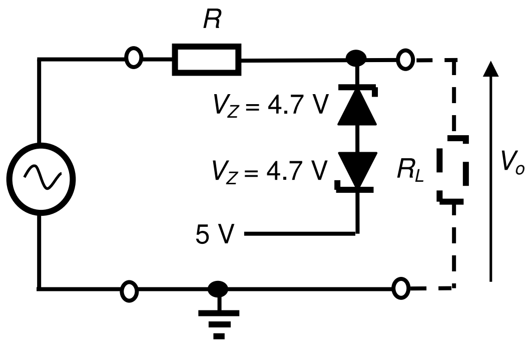
16.22 Here the rate of change of voltage is unchanged but the period of the discharge is halved. Therefore the voltage will fall by 10 ms × 455 V/s = 4.5 volts, which is half as much as before.

16.23



16.24 The circuits for this simulation exercise can be easily obtained by modifying the circuits of the demonstration files for Simulation Exercise 16.5.

16.25 A suitable (though not unique) circuit is



16.26 The circuit for this simulation exercise can be easily obtained by modifying one the circuits of the demonstration files for Simulation Exercise 16.5.