Answers to Coursebook questions – Chapter F5

1 The voltage at which saturation occurs is $\pm\frac{15}{10^5} = \pm 1.5\times 10^{-4}\ \text{V} = \pm 150\ \mu\text{V}$.

a Output will saturate to 15 V

b $V_0 = G(V_+ - V_-) = 10^5 \times 120 = 12\ \text{V}$

c $V_0 = G(V_+ - V_-) = 10^5 \times (-80) = -8.0\ \text{V}$

d Output will saturate to $-15\ \text{V}$.

2 **a** The output of the amplifier is proportional to the difference in the two input voltages such that $V_0 = G(V_+ - V_-)$.
The open loop gain is the constant of proportionality in this equation.
Saturation means that the output of the amplifier is equal to one of the voltages of the supply lines.

b The voltage at which saturation occurs is $\pm\frac{9.0}{10^5} = \pm 9.0\times 10^{-5}\ \text{V} = \pm 90\ \mu\text{V}$.
So, from $-90\ \mu\text{V}$ to $+90\ \mu\text{V}$.

3 The amplifier on the left has a gain of $-\frac{1.0\times 10^6}{100\times 10^3} = -10$
and that on the right a gain of $-\frac{2.0\times 10^6}{100\times 10^3} = -20$ for an overall gain of 200.

4 The equivalence is obvious – all you have to do is deform the circuit of this question (by 'stretching wires') to make it become the conventional circuit (see page 588 in *Physics for the IB Diploma*). Or equivalently, notice that both circuits have the same inverting and non-inverting input voltages.

5 **a** There can be no resistance in the feedback loop and so $R_F = 0$. No current can move from the non-inverting input to the zero volt line and so the resistance between these points must be infinite, so $R = \infty$.

b The gain of any non-inverting amplifier is $G = 1 + \frac{R_F}{R}$ so in this particular one the gain is $G = 1 + \frac{0}{\infty} = 1$.

c Amplifiers with gain 1 are useful for a variety of applications – one is described in the next problem.

6 **a** The voltages across the two resistors are equal and add up to 6.0 V, so each is 3.0 V.

b The total resistance of R_2 and the voltmeter is $\frac{1}{1.0}+\frac{1}{1.0}=\frac{1}{R_T}$ so $R_T = 0.5\,\text{k}\Omega$.

Now the voltage across R_2 and the voltmeter is half that across R_1.
The two voltages still add up to 6.0 V, so the reading of the voltmeter is 2.0 V.
The voltmeter reads the 'wrong' voltage – which we expected to be 3.0 V.
This is because this voltmeter does not have an infinite resistance, i.e. a resistance much higher than that of R_2.

c The voltage at the non-inverting input is 3.0 V. The amplifier has gain of 1 and so the output voltage (which is what the voltmeter reads) is $1\times 3.0 = 3.0\text{ V}$.

7 **a** We are assuming that the voltage at point V is that of earth, i.e. zero.

b See page 586 in *Physics for the IB Diploma*.

c The current through resistor R_1 is $\frac{V_{\text{in}}}{R_1}$. We are told that the current through R_F equals $I = I_0 e^{-kV} = I_0 e^{kV_0}$. The two currents are equal and so $\frac{V_{\text{in}}}{R_1} = I_0 e^{kV_0}$.

Taking logarithms gives $\ln(\frac{V_{\text{in}}}{I_0 R_1}) = kV_0$ and hence $V_0 = \frac{1}{k}\ln(\frac{V_{\text{in}}}{I_0 R_1})$.

d The amplifier can now handle a much greater range of input voltages since the output depends logarithmically on the input voltage.

8 The gain of the amplifier is 1 (see **Q5** and **Q6**). Thus the voltmeter reads the potential difference across the capacitor. Since the potential difference is proportional to the charge on the capacitor, the voltmeter can be calibrated to read charge; in other words it becomes a coulombmeter.

9 **a** The voltage at X is 0 by the virtual earth approximation.

b $I = \frac{V}{R} = \frac{4.00\times 10^{-3}}{250\times 10^{3}} = 0.016\times 10^{-6}\text{ A} = 16\text{ nA}$.

c The gain of the amplifier is $G = -\frac{500}{250} = -2.0$ and so $V_0 = -2.0\times 4.00 = -8.0\text{ mV}$.

10 **a** The voltage is (using the potential dividers idea) $\frac{15}{15+60}\times 15 = 3.0\text{ V}$.

b To saturate the output at -15 V the non-inverting input voltage must fall below 3.0 V. Assuming a voltage of 3.0 V at the junction between the 4.0 and 8.0 $\text{k}\Omega$ resistors means that the current through the $8.0\text{ k}\Omega$ resistor will be $\frac{12}{8.0} = 1.5\times 10^{-3}\text{ A}$ and the potential difference across the $4.0\text{ k}\Omega$ will be $4.0\times 1.5\times 10^{-3} = 6.0\text{ V}$. This means that the input voltage must then be $3.0 - V_{\text{in}} = 6.0 \Rightarrow V_{\text{in}} = -3.0\text{ V}$ so the input voltage must be reduced by 9.0 V.

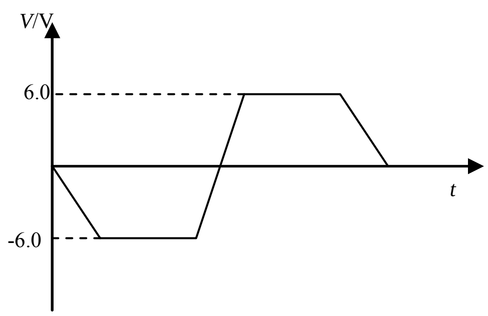
11 At $t = 0$ the voltage at the both inputs is zero. As time increases, the voltage at the non-inverting input is positive and therefore greater than the voltage at the inverting input. The output is positive and so current can move down through the diode. The potential difference across the capacitor is equal to the voltage of the input signal.
At $t = 0.5\text{ s}$ this potential difference is equal to the maximum input voltage, V_{max}.
The voltage at the inverting is also V_{max}.
After $t = 0.5\text{ s}$, the voltage at the non-inverting input will be less than that at the inverting input. Therefore the output will be negative and no current will move through the diode. This means that the voltage across the capacitor will remain to be V_{max}.

12 **a** The gain is $G = -\frac{32}{16} = -2.0$ and so the output is $V_0 = -2.0\times 4.0 = -8.0\text{ V}$.

b The maximum input voltage is 4.0 V and so the output never saturates. Thus we will have a graph that is -2.0 times the given graph (see page 814 in *Physics for the IB Diploma*).

c With a power supply of $\pm 6.0\text{ V}$ there would be saturation at $\pm\frac{6.0}{2.0} = \pm 3.0\text{ V}$.

The graph would then be something like:



13 The Schmitt trigger uses the comparator property of an op-amp (i.e. the output depends on whether the input signal is smaller or greater than a reference voltage value) except that there are two reference voltage values that the input signal is compared to. There is one value when the input signal is increasing and another when it is decreasing.

