3-1 The input voltage is given as a sine wave (starts at 0 and time 0) and is shown in blue on each of these graphs. The relative amplitude of the output voltage will depend upon the values of R and C for parts a, d, and e, and a scaling factor has been chosen arbitrarily to highlight the phase relationship between the signals. The amplitude relationship for b and c are correct.

**Problem 3-1(a) Amplifier**

Because the input signal is attached to the inverting input, the output signal is 180° out of phase with the input signal. The amplitude difference reflects that this is an amplifier. The magnitude is controlled by the relative magnitude of the two resistors, but is not specified here.

**Problem 3-1 (b) Voltage Follower**

The voltage follower’s input is the non-inverting input and with unity gain, the output exactly follows the input, but is buffered so that loading problems can be avoided.
This is a comparator circuit. The huge gain of the open loop op amp means that the transition between the output limits of the device happens very quickly when the polarity of the input signal changes sign. The change is so quick that it is almost a square wave. The input is into the inverting output so the sign is opposite.

Here we have an integrator. We also have the input signal connected to the inverting input. Hence, whenever the input signal is positive, the output signal becomes proportionally more negative; when input is negative, the output goes more positive. Because of the phase where we started, the output here is always negative, but that would be scaled and shifted according to the choice of components. The amplitude is also arbitrarily chosen here to emphasize the phase relationship.
This is a differentiator circuit. Note how it is zero when the input’s slope is zero (at the maximum or minimum) and it is at a maximum value when the input is going through zero. The input is also connected to the inverting input so the output is most negative when the input’s slope is most positive.

3-3. The rise time of an op amp circuit is given to be the reciprocal of 3 times its bandwidth. The slew rate gives the maximum rate of change of the output in response to a step change at the input. To calculate the slew rate, we must assume a voltage range. The book took 5 V. Most op amps have an output maximum of 10 V or 15 V. Any reasonable voltage range you chose will be marked correct if calculated correctly. I will use 5 V for the output voltage change.

\[ t_{\text{rise}} = \frac{1}{3\Delta f} = \frac{1}{3(50 \text{ MHz})} = 6.7 \text{ ns} \]
\[ r_{\text{slew}} = \frac{\Delta V}{\Delta t} = \frac{5 \text{ V}}{6.7 \text{ ns}} = 7.5 \times 10^8 \text{ V/s} = 750 \text{ V/\mu s} \]

3-5. This is a summing circuit. The negative sign in front of the output suggests that the inputs are summed into the inverting input of the last amplifier stage. Also, we need to invert \( V_3 \) before summing it. Then we need to choose resistor combinations to get the various coefficients. We note that 30 is a number which has all three coefficients (3, 5, and 6) as divisors.

First we invert \( V_3 \). This can be done using a simple voltage follower with the input into the inverting terminal. This circuit is called an inverter. One could also include resistors with the same resistance in the input and feedback positions so that you have a unity gain amplifier. Either one would work.

Next we choose the resistors. Recall that the gain is the ratio of the feedback resistor to the input resistor. If we let the feedback resistor be 30 \( \Omega \), the the input resistor for \( V_1 \) would be
10 \, \Omega, \text{ for } V_2 \text{ it would be } 6 \, \Omega, \text{ and for } V_3 \text{ it would be } 5 \, \Omega. \text{ These small resistances are not normally used, because small resistances elsewhere would shift the output significantly. Multiply everything by 100 and you have the same gains, but with more stability.}

3-10. Look at the first op amp. Clearly the voltages will be inverted. They will be amplified by the ratio of the feedback to input resistors. Hence, $V_1$ will be amplified $15/3 = 5$; $V_2$ will be amplified $15/5 = 3$. The voltage at the output of the first op amp will be $-5V_1 - 3V_2$.

At the second op amp, all voltages are inverted. The amplifications are $12/6 = 2$ for the combination of $V_1$ and $V_2$; $12/4 = 3$ for $V_3$; $12/6 = 2$ for $V_4$. The end result is

$$V_{output} = -2(-5V_1 - 3V_2) - 3V_3 - 2V_4 = 10V_1 + 6V_2 - 3V_3 - 2V_4$$

3-14. Here we have an integrator with two summing inputs. They are summed at the inverting input. With $R_1 = 20 \, \text{M}\Omega$ and $R_2 = 5 \, \text{M}\Omega$ and $C = 0.01 \, \mu\text{F}$ we can write the expression for the output voltage as

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} = -C \frac{dV_{out}}{dt}$$

$$\int dV_{out} = \int -\frac{1}{C} \left[ \frac{V_1}{R_1} + \frac{V_2}{R_2} \right] dt$$

$$V_{out} = -\frac{1}{C} \int_0^t \left[ \frac{V_1}{R_1} + \frac{V_2}{R_2} \right] dt = -\int_0^t \left[ 5V_1 + 20V_2 \right] dt$$

If the input voltages are constant in time, then they could be brought out of the integral but this form allows for them to be time varying themselves.
3-18. Here we need to sum the output of the integrator with two more voltages. Note that the other two voltages are inverted. The first voltage is integrated with a multiplicative factor of 1. This means that the magnitude of the resistance must balance that of the capacitance so as to give 1 for the RC constant. We could use 1 MΩ and 1 µF (the M cancels the µ nicely). This output, and that of the other two inputs need to be summed and amplified by factors of 2 and 6. They are both factors of 6. The input resistors for $V_2$ and $V_3$ are 1 MΩ and that for the integral of $V_1$ is 3 MΩ. Then with a feedback resistor of 6 MΩ, we have the appropriate relationship.