Possibly useful equations:

\[ V = IR \quad \quad \quad \quad \quad v_{rms} = \sqrt{4kTR\Delta f} \quad \quad \quad \quad \quad i_{rms} = \sqrt{2le^{-\Delta f}} \]

\[ A = \varepsilon b c \quad \quad \quad \lambda = \frac{2dn^*}{n} \quad \quad \quad n\lambda = d(\sin i + \sin r) \]

\[ \frac{\Delta r}{\Delta \lambda} = \frac{n}{d \cos r} \quad \quad \quad v_Mr = \frac{\lambda}{4} \quad \quad \quad R(\text{cm}^2) = \frac{1}{\delta_{\text{max}}} \]

\[ \Delta \delta = \frac{1}{2\Delta \delta} \]

Please read the questions carefully and follow instructions. Be sure that your handwriting is clear, and indicate your answer. Use the correct units and a reasonable number of sig figs. If calculations are required, show your work in order to receive full or partial credit.

1. (3 pts) Choose the one correct answer:

Which of the following is one of Kirchhoff’s Laws?

a. The current entering any point on a circuit in parallel must equal the current at all other points.

b. The voltage drop around a complete circuit in series must equal the input voltage.

c. Current is inversely proportional to resistance.

d. None of the above.

2. (4 pts) What is the voltage drop across \( R_1 \) in the circuit below?

![Circuit Diagram]

3. (5 pts) If \( R_1 \) (above) has a value of 3M\( \Omega \), what is the current (I) through the circuit?

\[ I = \frac{V}{R} = \frac{5V}{3 \times 10^6 \Omega} = 1.7 \times 10^{-6} A \]
Consider the circuit below for questions 4, 5, and 6.

\[ R_T = 55\, \text{k}\Omega + 30\, \text{k}\Omega + \left[ \frac{1}{60\, \text{k}\Omega + 50\, \text{k}\Omega} \right] \]

\[ R_T = 110\, \text{k}\Omega \]

4. (5 pts) What is the current (I) through point B?

\[ I = \frac{V}{R} = \frac{15\, \text{V}}{110\, \text{k}\Omega} = 1.4 \times 10^{-4} \, \text{A} \]

5. (5 pts) What is the current (I) through point A?

Since \( R_1 = R_2 \), then

\[ I_A = \frac{1}{2} I_B = 6.8 \times 10^{-5} \, \text{A} \]

6. (5 pts) What is the voltage (V) (with respect to ground) at point B?

\[ V_B = \left[ \frac{55\, \text{k}\Omega}{(110+55)\, \text{k}\Omega} \right] 15\, \text{V} = 7.5\, \text{V} \]

7. (4 pts) Choose the one correct answer:

As an RC circuit is charging, the following is true:

a. The voltage across the resistor is decreasing.
b. The voltage across the capacitor is increasing.
c. The current across the resistor is increasing.
d. Both a. and b. are true.
e. Both a. and c. are true.
f. Both b. and c. are true.

8. (4 pts) For an ideal op-amp the gain is \textit{infinite}.

9. (6 pts) For an ideal op-amp the input resistance is infinite. Why can't this be true for a real op-amp (Explain in terms of \( V_{out} \))?

If input resistance is infinite, then no current enters the op-amp. In that case there would be no relationship between \( V_{in} \) and \( V_{out} \) and you would not have an amplifier.
10. (6 pts) What is the resolution (expressed in volts(V)) of an 11-bit A/D converter with an input voltage range of 0-10V?

\[
\frac{10V}{2^n} = 4.9 \times 10^{-3} V
\]

11. (5 pts) Express the following binary numbers in their decimal form:

a. 100101
   \[ \underline{37} \]
   \[ \underline{2} \]

b. 10

12. (3 pts) Indicate if the following is true or false:

Flicker noise is generally ‘high’ frequency relative to the signal.

13. (3 pts) Indicate if the following is true or false:

Thermal noise can be completely eliminated by lowering temperature to 0°C.

14. (6 pts) Student A and Student B both carried out identical analyses on the same instrument. Student A repeated the experiment 5 times. Student B repeated the experiment 15 times. By what factor is student B’s S/N better than Student A’s?

\[
\frac{\sqrt{15}}{\sqrt{5}} = \sqrt{3}
\]

15. (5 pts) Why would someone use boxcar averaging instead of ensemble averaging?

Boxcar averaging is used when it is impossible to make multiple scans of a sample.

16. (6 pts) You are designing a spectrometer. Choose the appropriate components below to make either a (circle one): Visible spectrometer or a FTIR spectrometer.

Circle one of each of the appropriate components below for the type of spectrometer you chose above:

- Light source → wavelength selector → sample holder → detector

  V a. tungsten lamp  V a. monochromator  F a. KBr cell
  F b. globar  F b. interferometer  V b. quartz cell
  V a. photomultiplier  F b. photoconductor
17. (8 pts) For a grating with a blaze spacing of 1200blazes/mm and an incident angle of $30^\circ$ for incoming radiation, what is the 1$^{\text{st}}$ order angle of reflection (reported in degrees) for light of 400nm? ($\pi$ radians = $180^\circ$, $\pi = 3.14159$).

$$n = 1$$
$$\lambda = 400\text{nm}$$
$$d = \frac{1}{1200\text{nm}} = 833\text{nm}$$
$$i = 30^\circ$$

$$\sin i = \frac{\sin i + \sin r}{\sin i}$$

Solve for $r$

$$(1)(400\text{nm}) = 833\text{nm} (\sin 30^\circ + \sin r)$$

$$\sin r = -0.0192$$

$$r = \sin^-1(-0.0192)$$

$$r = -0.0192 \text{ rad} = -1.10^\circ$$

18. (6 pts) For the same grating described in problem 17, calculate the 1$^{\text{st}}$ order dispersion (reported in degrees/nm); use the reflection angle that you calculated in question 17.

$$\frac{\Delta r}{\Delta \lambda} = \frac{1}{833\text{nm} \cos -1.10^\circ} = 1.20 \times 10^{-3} \text{ rad/} \text{nm} = 0.069^\circ \text{/nm}$$

19. (3 pts) Choose the one correct answer:

For a Michelson interferometer, the resolution is dependent on:

a. The spacing at which measurements are made as the mirror moves.
b. The total distance that the mirror moves during a single scan.
c. The speed at which the mirror moves.
d. None of the above.

20. (8 pts) You are designing an FTIR spectrometer. You would like your spectrometer to scan the wavenumber range 4800cm$^{-1}$ to 400cm$^{-1}$, and have a resolution of 0.15cm$^{-1}$. Your detector has a time constant of 5000Hz. Specify how fast (cm/s) the interferometer mirror can move, at what mirror distance interval (cm) must signals be collected, and how far the mirror must travel in total (cm).

Resolution: $R = \frac{1}{\Delta \lambda_{\text{max}}}$

0.15 cm$^{-1} = \frac{1}{\Delta \lambda_{\text{max}}}$

$\Delta \lambda_{\text{max}} = 6.7\text{cm}$

Maximum mirror travel = $\frac{6.7}{2} = 3.3\text{cm}$

Wavenumber range: $\Delta \delta = \frac{1}{2\Delta \lambda_{\text{max}}} = \frac{1}{2(4800\text{cm}^{-1})}$

$\Delta \delta = 1.04\mu\text{m}$

$\frac{2}{\Delta \delta} = 2 \times 5000\text{ s}^{-1}$

$\frac{1}{\Delta \delta} = 4 \times 5000\text{ s}^{-1}$

$V_{\text{m}} = \frac{f}{\Delta \delta} = \frac{5000\text{ s}^{-1}}{4} = 1250\text{ cm/s}$

$V_{\text{m}} = \frac{f}{4\Delta \delta} = \frac{5000\text{ s}^{-1}}{4(4800\text{cm}^{-1})}$

$\frac{V_{\text{m}}}{4\Delta \delta} = 0.26\text{ cm/s}$