Possibly useful equations:

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

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

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

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

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 series must equal the current at all other points.
   b. Current is inversely proportional to resistance.
   c. The voltage drop around a complete circuit in series must equal zero.
   d. None of the above.

2. (4 pts) What is the current through \( R_1 \) in the circuit below if \( R_1 = 1\,\text{k}\Omega \)?

   \[ \begin{array}{c}
   5V
   \end{array} \quad \frac{1}{\Omega} \quad \begin{array}{c}
   R_1
   \end{array} \]

   \[ I = \frac{V}{R} = \frac{5V}{1000\,\Omega} = 5 \times 10^{-3}\,\text{A} \]

3. (5 pts) If \( R_1 \) (above) has a value of 3\,\text{M}\Omega, what is the voltage drop across \( R_1 \)?

   \[ 5V \]
Consider the circuit below for questions 4, 5, and 6 with $R_1 = 200\Omega$ and $R_2 = 250\Omega$.

4. (5 pts) What is the current through $R_2$?

$$R_T = R_1 + R_2 = 450\Omega$$

$$I = \frac{V}{R} = \frac{5V}{450\Omega} = 0.01A$$

5. (5 pts) What is the voltage drop across $R_2$?

$$V_{R_2} = \frac{250}{450} (5V) = 2.8V$$

6. (5 pts) What is $V_{out}$ (positive lead on the left and negative on the right)?

$$V_{left} = 2.5V$$

$$V_{right} = 5V - 2.8V = 2.2V$$

$$V_{out} = 2.5 - 2.2 = 0.3V$$

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

For a simple low-pass signal filter we should measure $V_{out}$ across what in an RC circuit?

a. The resistor.

b. The capacitor.

c. Both the resistor and capacitor

d. Neither the resistor or the capacitor.

8. (6 pts) For the op-amp below, express $V_{out}$ in terms of $V_{in}$, $R_1$, and $R_2$.

$$I_{R_2} = -I_{R_1}$$

$$\frac{V_{in}}{R_1} = -\frac{V_{out}}{R_2}$$

$$V_{out} = -\frac{R_2}{R_1} V_{in}$$
9. (4 pts) What is the ‘gain’ for the op-amp in question 8?

\[ \frac{-R_2}{R_1} \]

10. (6 pts) What is the resolution (expressed in \( \mu V \)) of an 18-bit A/D converter with an input voltage range of 0-5V?

\[ \frac{5}{2^{18}} \times 10^6 = \frac{19 \mu V}{c} \]

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

a. 83

\[ \text{1010011} \]

b. \( 1 \times 10^4 \)

\[ \text{10011100010000} \]

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

Environmental noise is always at one specific frequency.

True

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

Thermal noise can theoretically be eliminated by lowering temperature to 0 Kelvin.

False

14. (6 pts) A specific protocol requires a S/N of 3.0 for data to be considered acceptable. For a particular sample, a single analysis on the specified instrumentation gives an S/N of 1.5 due to random baseline noise. How many total analyses should be made of this sample to achieve an S/N of 3 with the averaged results?

\[ 1.5 \sqrt{n} = 3.0 \]

\[ \sqrt{n} = 2 \]

\[ n = 4 \]

15. (5 pts) What is the major difference between boxcar averaging and a running average?

All points are independent in boxcar average - lower total points

In running average each point has some dependence on adjacent points

16. (6 pts) Draw the schematic diagram for a UV/VIS spectrometer. It must include the 5 general components of a spectrometer.
17. (8 pts) For a grating with a blaze spacing of 1500blazes/mm and an incident angle of 30° (relative to grating normal) for incoming radiation, what is the 1st order wavelength of light (reported in nm) with an angle of reflection of 5° (relative to grating normal)? (π radians = 180°; π = 3.14159).

\[
\begin{align*}
\text{1500 blazes/mm} &= 667\text{mm/blaze} \\
I(\lambda) &= 667\text{nm} (\sin 30° + \sin 5°) \\
\lambda &= 392\text{ nm}
\end{align*}
\]

18. (6 pts) Why can’t the grating described in problem 17 be used to separate 1st order wavelengths greater than ~1000nm when the incident angle is 30°?

\[
1000\text{nm} = 667(\sin 30° + \sin r)
\]

\[
\sin r = 1.0 \\
r = 90°
\]

The reflection angle is greater than 90°, which would be below the plane of the grating.

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

For a Michelson interferometer, the wavelength range scanned is dependent on:

a. The spacing (Δδ) 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 wavenumbers to 5000cm⁻¹. Ideally, what wavelength (reported in nm) of laser light should you use to control the motion of the moveable mirror and sampling interval of your Michelson Interferometer if data is collected at every second maximum observed in the interferogram of the laser?

\[
\Delta \delta = \frac{1}{2(5000\text{ cm}^{-1})} = \frac{1 \times 10^{-4} \text{ cm}}{2} = 5 \times 10^{-5} \text{ cm} = \frac{500\text{ nm}}{10\text{ cm}} \text{ of mirror movement/data point collected}
\]