Possibly useful equations:

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

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

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

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

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. (6 pts) Identify each of the following as either Ohm's law, or one of Kirchhoff's laws.
   a. The sum of all currents flowing into any point in a complete circuit must equal the sum of all currents flowing out of that same point. \( \text{Kirchhoff} \)
   b. Voltage equals the product of current and resistance. \( \text{Ohm} \)
   c. The sum of the voltage drops across each element of a complete circuit in series must equal the input voltage. \( \text{Kirchhoff} \)

2. (6 pts) If the current passing through \( R_1 \) is 0.625mA, and the input voltage is 5V, what is the resistance of \( R_1 \)?

\[
V = IR
\]

\[
R = \frac{V}{I} = \frac{5V}{0.625 \times 10^{-3} A} = \frac{8000}{2}
\]

3. (4 pts) If the voltage drop across \( R_1 \) (above) is 7.5V, what is the input voltage?

\[
7.5V
\]
Consider the circuit below for questions 4, 5, and 6 with \( R_1 = 200\Omega \) and \( R_2 = 250\Omega \) (notice that there are two \( R_1 \) and two \( R_2 \) resistors).

4. (6 pts) What is the current through \( R_2 \)?

\[
R_{\text{tot through left}} = 450\Omega
\]

\[
I = \frac{V}{R} = \frac{5V}{450\Omega} = \boxed{0.011 \text{ amps}}
\]

5. (6 pts) What is the voltage drop across \( R_2 \)?

\[
V_{R_2} = V_{\text{tot}} \left( \frac{R_2}{R_1 + R_2} \right) = 5V \left( \frac{250\Omega}{450\Omega} \right) = \boxed{2.78V}
\]

- is the same for either \( R_2 \)

6. (7 pts) What is \( V_{\text{out}} \) (negative lead on the left and positive on the right)?

\[
V_{\text{out, left}} = (5 - 2.78) = 2.22V
\]

\[
V_{\text{out, right}} = 2.78V
\]

\[
2.78 - 2.22 = \boxed{0.56V}
\]

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

For a simple high-pass signal filter we should measure \( V_{\text{out}} \) across what in an RC circuit?

\[\boxed{a. \text{ The resistor.}}\]

\[\boxed{b. \text{ The capacitor.}}\]

\[\boxed{c. \text{ Both the resistor and capacitor}}\]

\[\boxed{d. \text{ Neither the resistor or the capacitor.}}\]

8. (7 pts) What resolution A/D converter (how many bits) is necessary to record data with a precision of 1 part in 244 million?

\[
2^n = 244 \times 10^6
\]

\[
\log_2 n = \log(244 \times 10^6)
\]

\[
n = \boxed{28.6 \text{ bits}}
\]
9. **(4 pts)** Indicate if the following is true or false: 

Flicker noise is generally low frequency relative to the frequency of the signal. 

10. **(4 pts)** Indicate if the following is true or false: 

Shot noise cannot be completely eliminated. 

11. **(7 pts)** A specific protocol requires a minimum S/N of 10 for data to be considered acceptable. For a particular sample, a single analysis on the specified instrumentation gives an S/N of 3.3 due to random baseline noise. How many total analyses should be made of this sample to achieve a minimum S/N of 10 with the averaged results?

\[
\sqrt{n} \left(3.3\right) = 10 \\
\Rightarrow n = 9.18 \approx 10 \text{ measurements minimum}
\]

12. **(6 pts)** Does ensemble averaging reduce random or systematic noise? Briefly explain.

Reduces random noise. Averaging random variation around a mean will cancel the variation. If the variation was systematic, it would be reinforced by averaging.

13. **(10 pts)** 'Build' a spectrometer. Choose components from the lists below and put them in the proper order to represent a working spectrometer. Indicate the general wavelength range your spectrometer is designed for, whether or not it is to be used for absorption or emission measurements, and if it is capable of producing multi-wavelength spectra, fixed wavelength measurements, or both. You are not required to use an item from each list, you may use multiple items from each list or the same item more than once, and there are multiple correct answers.

Circle one: **UV-VIS or IR**
Circle one: absorption or emission
Circle one: spectra, constant \( \lambda \) measurements, or both?

<table>
<thead>
<tr>
<th>detector</th>
<th>wavelength selector</th>
<th>light source</th>
<th>sample 'holder'</th>
</tr>
</thead>
<tbody>
<tr>
<td>photodiode</td>
<td>interferometer</td>
<td>Nernst glower</td>
<td>KBr</td>
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<tr>
<td>photomultiplier</td>
<td>monochromator</td>
<td>hollow cathode lamp</td>
<td>flame</td>
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<tr>
<td>thermal transducer</td>
<td>interference filter</td>
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<td>NaCl</td>
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<td>laser</td>
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<td>glass</td>
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<td></td>
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<td>Hg vapor lamp</td>
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<td></td>
<td></td>
<td>tungsten filament lamp</td>
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</tr>
</tbody>
</table>

Make a diagram of your spectrometer here:

![Diagram of spectrometer](tungsten filament lamp → quartz → photodiode array)
14. (7 pts) For a grating with a blaze spacing of 1500 blazes/mm and an incident angle of 30° (relative to grating normal) for incoming radiation, what is the 2nd order wavelength of light (reported in nm) with an angle of reflection of 40° (relative to grating normal)? (π radians = 180°; π = 3.14159).

\[ \text{nd} = d \left( \sin i + \sin r \right) \]

\[ \lambda = \frac{667 \text{ nm} \left( \sin 30° + \sin 40° \right)}{2} \]

\[ = 381 \text{ nm} \]

15. (8 pts) To obtain a first order dispersion of 0.002 degrees/nm at a reflection angle of 20°, how many blazes/mm are required?

\[ \Delta r = \frac{\mu}{d \cos r} = \frac{1}{d \cos 20°} = 0.11 \text{ deg/mm} \]

\[ \Delta r = \frac{1}{1.92 \times 10^{-3} \text{ rad/mm}} \]

\[ d = 554 \text{ mm/blaze} \]

\[ = 5.54 \times 10^{-4} \text{ mm/blaze} = \frac{1804 \text{ blazes}}{\text{ mm}} \]

16. (8 pts) Give 2 reasons why you might choose to use ICP-MS rather than either flame AA or graphite furnace AA.

1. Lower detection limits
2. Ability to analyze multiple elements simultaneously