True/false questions:

___1. Low pass filters cause a measurable phase shift at input frequencies above the break frequency.

___2. With normally distributed data, less than 80% of the data will fall between the mean value and the mean value ±2σ.

___3. Passive filters always reduce the amplitude of the output signal compared to the input signal.

___4. Low input impedance is desirable in measuring devices, since they will draw very little current from the measured system.

___5. The minimum gain for an inverting op-amp circuit is 1.

___6. Error bars are placed on plots of experimental data to indicate the uncertainty associated with each measurement.

___7. Range is the difference between the minimum and maximum inputs that produces a valid output.

___8. Accuracy is the difference between “true” and measured values.

___9. Resolution is the difference among repeated measurements of the same quantity.

___10. Precision is the change in output per change in input (slope of output vs. input line).
Part 2: Closed book, closed notes, one 8.5x11 inch hand-written formula sheet allowed.

12. The input, $E_i(t)$ to each of the 5 circuits below is a 2.0 V_{p-p} sine wave at 100 Hz.
   - Describe (in words and/or equations) what each circuit "does" to the input signal.
   - Accurately sketch the output waveform $E_o(t)$ on the "scope" for each of the circuits.
   - Note that the input waveform $E_i(t)$ is already provided on each "scope" figure.

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**Figure 12-A**

- $E_i(t)$ and $E_o(t)$ are sine waves.
- The circuit consists of a simple inverting amplifier with a 20kΩ resistor.

**Figure 12-B**

- $E_i(t)$ and $E_o(t)$ are sine waves.
- The circuit includes a capacitor (0.047μF) and two resistors (56kΩ and 20kΩ).

**Figure 12-C**

- $E_i(t)$ and $E_o(t)$ are sine waves.
- The circuit features a non-inverting amplifier with resistors (20kΩ, 30kΩ) and a +1.0 volt source.
13. Six different measurements of the same DC voltage are listed in the table below.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.534V</td>
</tr>
<tr>
<td>2</td>
<td>3.510V</td>
</tr>
<tr>
<td>3</td>
<td>3.535V</td>
</tr>
<tr>
<td>4</td>
<td>3.529V</td>
</tr>
<tr>
<td>5</td>
<td>3.535V</td>
</tr>
<tr>
<td>6</td>
<td>3.525V</td>
</tr>
</tbody>
</table>

The mean value for the voltage readings is 3.528 volts.

a. Determine the standard deviation of the sample for the voltages.
b. Estimate the 95% confidence interval for the mean value.
c. If each of the voltage measurements given in the table above were subject to ±0.3% + 2 digit accuracy (due to the DMM), what would be your estimate of the total uncertainty for the mean voltage value?

14. The op-amp circuit shown above creates an output voltage $E_o = 4.567$ volts with an input of $E_i = 1.234$ volts. Each voltage measurement is subject to ±1% + 2 digit accuracy.

The tolerance on each resistor value is ±3% (no measurement of the resistors is available).

a. What is the experimental gain?
b. What is the uncertainty in the experimental gain?
c. What is the theoretical gain?
d. What is the uncertainty in the theoretical gain?
e. Do the experimental and theoretical values “overlap?”

15. You have been given a breadboard with a 741 op-amp, a selection of 10kΩ, 22kΩ, and 47kΩ resistors, as well as several short pieces of wire.

Design and completely wire a multiple input, summing amplifier with a gain of $-2.59$.

- input $E_1$ uses a blue/black wire pair,
- input $E_2$ uses an orange/black wire pair,
- output $E_{out}$ uses a yellow/black wire combination.

Resistor color codes:
- 10kΩ – Brown / Black / Orange
- 22kΩ – Red / Red / Orange
- 47kΩ – Yellow / Violet / Orange
1. Define in terms a bright high school student would understand the following terms related to instrumentation:
   - analog
   - linearity
   - sensitivity

2. What is "impedance?" What kind of impedance should a measuring device (like a DMM) have and why?

3. A set of 10 measurements is made of a single variable. Different results are obtained from each measurement. Outline the procedure for calculating the precision uncertainty of the measurements.

4a. A beam's thickness is measured to be 2 inches. About how many millimeters is this thickness? (round to the closest millimeter).

4b. An ME student has a mass of 75 kg. About how many lbm is this? (round to nearest lbm)

4c. A new car has an engine rated at 200 hp. About how many kilowatts is this? (round to closest kW)
5. A first order RC circuit is shown on the right.
   a) Select a capacitor from the table below such that the time constant is closest to 6 msec.

<table>
<thead>
<tr>
<th>Capacitor Value</th>
<th>0.001µF</th>
<th>0.0022µF</th>
<th>0.0047µF</th>
<th>0.01µF</th>
<th>0.022µF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Constant</td>
<td>0.6 m sec</td>
<td>0.3 m sec</td>
<td>0.15 m sec</td>
<td>0.6 m sec</td>
<td>0.3 m sec</td>
</tr>
</tbody>
</table>

   b) Sketch the output waveform on the diagram provided below if a 1.2 volt step input is applied as shown (the output voltage is initially -0.6 volts) with vertical sensitivity of 0.2 volts/div, horizontal sensitivity of 2 msec/div.
6a. Using a 12 bit, bipolar, $\pm 10$ volt A/D converter, what range of input voltages corresponds to a digital value of 1563?

6b. Using an 10 bit, unipolar, 0-5 volt A/D converter, what digital value would an input of +2.483 volts convert to?

7. A rotating mass creates an unbalanced force given by the formula $F = mr\omega^2$. Determine the nominal unbalanced force, $F$, and the uncertainty in the force, $U_F$, for the following nominal values and uncertainties.

- Mass, $m = 0.032 \pm 0.001$ kilogram
- Radius, $r = 0.456 \pm 0.020$ inch
- Speed, $\omega = 1775$ RPM $\pm 1\%$
8. Design an op-amp circuit that will convert the input voltages shown in the table to the associated output voltages. Assume that you have access to all of the resistors and potentiometers in the ME 360 lab downstairs.

a) Draw a schematic of your circuit. Label all parts of the circuit - tell what they do.

<table>
<thead>
<tr>
<th>Input, $E_{in}$ (mv)</th>
<th>Output, $E_{out}$ (volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.03</td>
</tr>
<tr>
<td>-5</td>
<td>1.74</td>
</tr>
<tr>
<td>-20</td>
<td>2.44</td>
</tr>
<tr>
<td>-45</td>
<td>3.62</td>
</tr>
</tbody>
</table>

b) Draw your circuit on the breadboard below. Show all power and input/output connections to the circuit. Draw resistors like this.