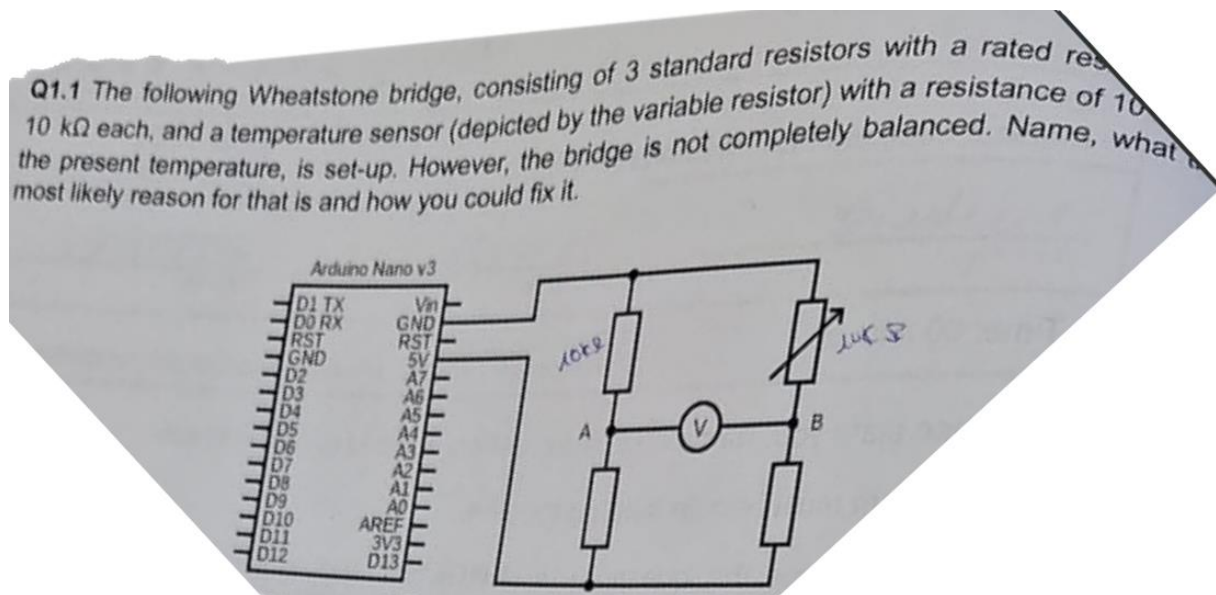
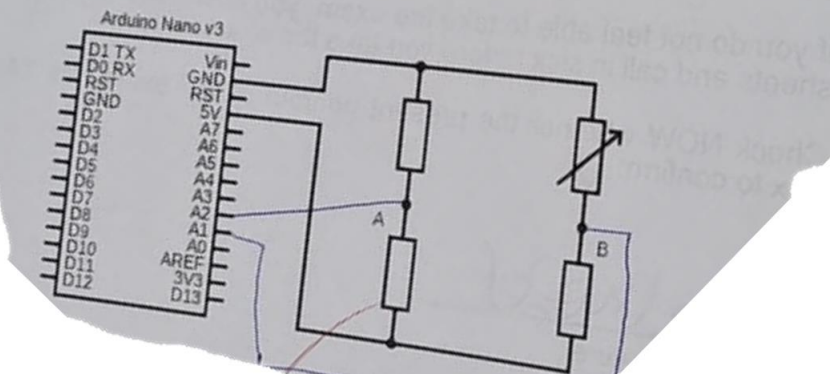


Question 1: Arduino (5 Points)



2 Points

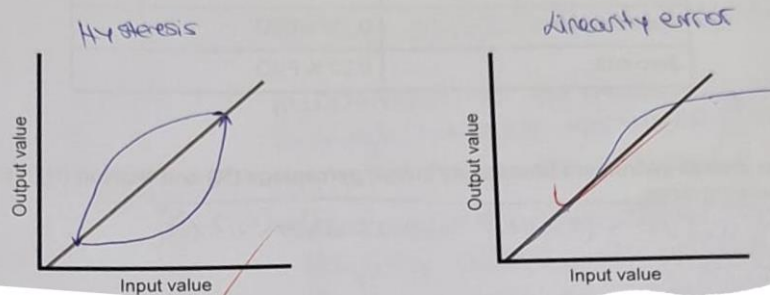
- Q1.2** Using the same setup as in Q1.1 and assuming that the bridge is balanced now, you want to measure the bridge voltage (between A and B) with your Arduino. Therefore, you plan to do the following:
- Connect A and B to any suitable pins of your Arduino by drawing lines into the circuit.
 - To interpret the measured value, calculate the resolution of the 0-5 V 10-bit Analog-to-Digital Converter (ADC) on the ATmega328P in volts. Assume a sufficient supply voltage.
 - The readout for the bridge voltage now is 300. Calculate the actual bridge voltage V_{AB} in volt, using the previously determined resolution.



3 Points

Question 2: Measurement Systems (9 Points)

Q2.1 You are now extremely happy that you just managed to calibrate your force sensor. However, your calibrated force sensor is still providing **erroneous measurements**. **Name** and **describe 2 types of error** that your sensor could be exhibiting and **sketch** what this may look like relative to the plotted lines below. Note, a linear response is considered ideal.



2 points

Q2.2 In an attempt to improve the measurement uncertainty of a force sensor, $\pm 0.5 \text{ N}$, you take **eight measurements** of the same weight applied on your force sensor. Assuming you average the value of all eight measurements, **calculate** the **new measurement uncertainty of the averaged measurement**.

2 Points

Q2.3 Assume a force sensor has the following specifications:

Range	0 to 1000 N
Linearity error	0.10 % FSO
Hysteresis error	0.10 % FSO
Sensitivity error	0.15 % FSO
Zero drift:	0.20 % FSO

Estimate the **overall instrument uncertainty** in both **percentage (%)** and **Newton (N)**. FSO refers to full-scale operating range.

2 Points

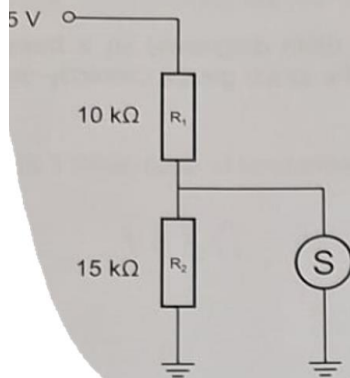
Q2.4 You are given two different force sensors in one of the MMM labs. The first one (FS1) is very accurate but not very precise. The second one (FS2) has a low accuracy but a high precision. Illustrate each sensor behavior unambiguously in respect to precision and accuracy on the target by adding 5 crosses representing 5 measurements. Circle the sensor you would continue with and draw an arrow to indicate how a calibration would shift the crosses on the target.



3 Points

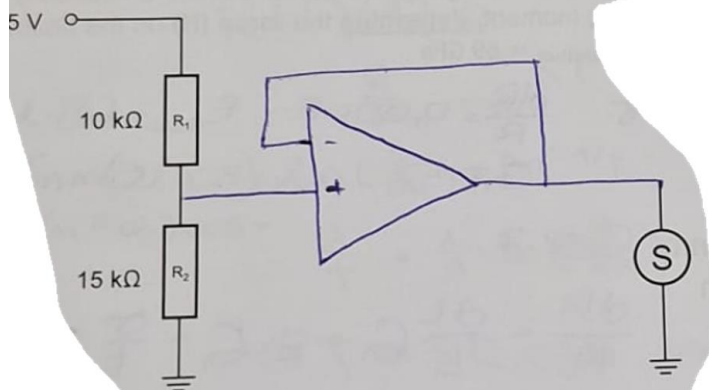
Question 3: Operational Amplifiers (5 Points)

Q3.1 For a measurement setup, you need to supply your sensor (S) with a voltage of 3 V. However, your Arduino only outputs 5 V. To divide the voltage accordingly, you set up a **voltage divider** consisting of a resistor with $R_1 = 10 \text{ k}\Omega$ and a second one with $R_2 = 15 \text{ k}\Omega$. However, the voltage measured directly at the sensor's connections **differs from the expected 3 V**. Briefly describe what the **most likely problem** is.



2 Points

Q3.2 What **circuitry** could you add to **solve this problem** and **why**? Think of operational amplifiers. Add your circuitry to the voltage divider and sensor by drawing it into the following circuit sketch.



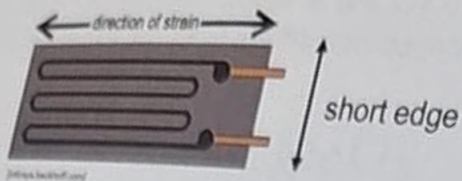
1 Point

Q3.3 State **two general ways** how an instrumentation amplifier can **induce error** into the amplified signal.

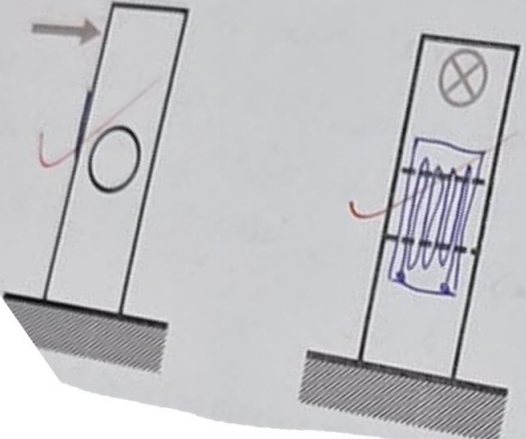
2 Points

Question 4: Force (5 Points)

A digital scale is used to measure the weight of a patient. It consists of multiple load cells to measure the gravitational force of a patient.

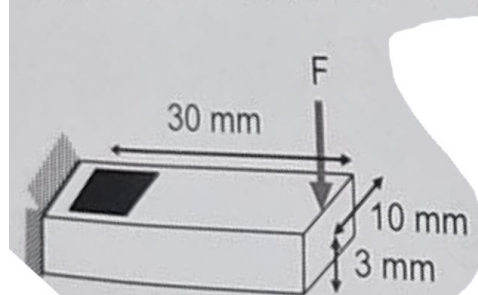


Q4.1 Using the load cell below, **place** 1 strain gauge on the beam (both diagrams) so a bending moment can be measured. **Indicate** direction of strain by **orienting** the strain gauge correctly on the beam (see figure above).



1 Point

Q4.2 Assuming the following aluminium beam and strain gauge (assume correct orientation) are used ($GF = 2.0$) to measure the maximum bending moment, **determine** the force (N) on the beam if a change in resistance of 0.02 % is measured. $E_{\text{aluminium}} = 69 \text{ GPa}$



4 Points

Question 5: Temperature (12 Points)

You are assigned with the task of measuring the temperature of blood inside an artificial heart to enable control of the blood temperature. We can expect the blood temperature to range between 30-45 °C. Assume 0 °C = 273 K.

Assuming a **TTC05222** temperature sensor is used (datasheet on the page 9), determine the following.

Q5.1 What **type** of temperature sensor is this? How does it **change** with temperature?

2 Points

Q5.2 Assuming a resistance of **1.2 kΩ** is measured. Using the datasheet, **determine** the temperature of the sensor in degrees **Celsius**. Hint, take note of the units used.

TTC05222 temperature sensor is used (datasheet below). Take note of units.

NTC Thermistor: TTC05 Series

Φ5 mm Disc Type for Temperature Sensing/Compensation

■ Electrical Characteristics

Part No.	Zero Power Resistance at 25°C	Tolerance of R ₂₅	B _{25/50} Value	Max. Power Rating at 25°C	Dissipation Factor	Thermal Time Constant	Operating Temperature Range	Safety Approvals			
	R ₂₅ (Ω)	(±%)	(K)	P _{max} (mW)	δ(mW/°C)	τ(Sec.)	T _L ~T _U (°C)	UL	CSA	TUV	CQC
TTC05005	5	5 · 10 · 15	2400	450	Approx. 4.5	Approx. 20	-30~+125				
TTC05010	10		2800								
TTC05015	15		2800								
TTC05020	20		2800								
TTC05301	300		3800								
TTC05471	470		3500								
TTC05501	500		3700								
TTC05681	680		3800								
TTC05701	700		3800								
TTC05102	1000		3800								
TTC05152	1500		3950								
TTC05202	2000		4000								
TTC05222	2200		4000								
TTC05252	2500		4000								
TTC05302	3000		4000								
TTC05332	3300		4000								
TTC05402	4000		4000								
TTC05204	200000		4600								
TTC05224	220000		4600								
TTC05474	470000		4750								

Note : □ = Tolerance of R₂₅

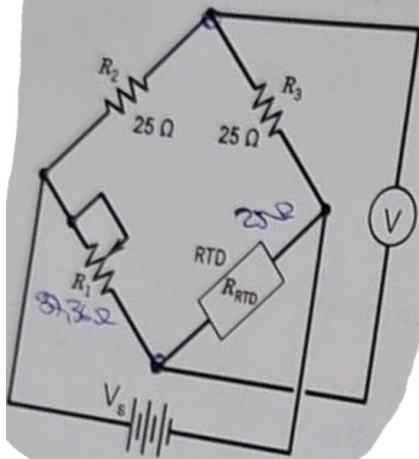
Note2 : UL file no. E138827
CSA file no. 97495
TUV file no. R 50050155
CQC file no. CQC05001011991 : CQC05001011994

4 Points

Q5.3 Briefly **describe** what influence **long wire/leg length** of the sensor would have on the measurement. **Explain** how the measurement may change.

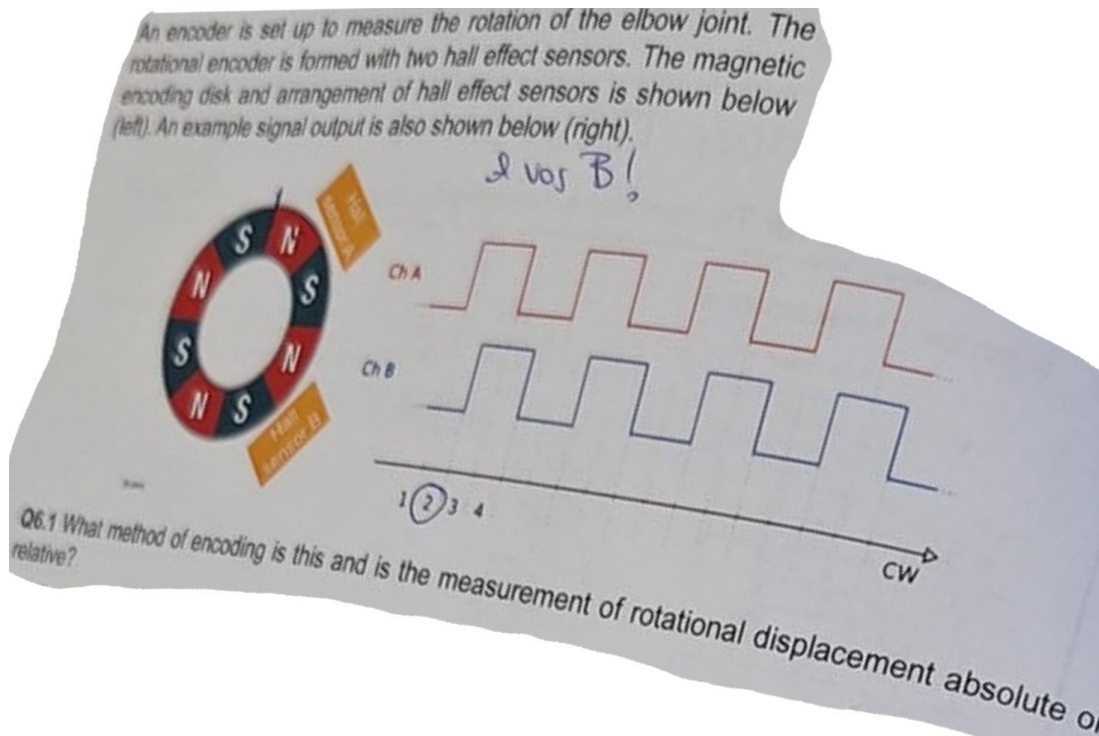
2 Points

Q5.4 You are assigned with the task of measuring the temperature inside a medical device. You have chosen a resistance temperature detector (RTD) and have already set up a suitable Wheatstone bridge. The RTD has a resistance of $25\ \Omega$ at a temperature of $0\ ^\circ\text{C}$. The temperature coefficient of resistance is $\alpha = 0.003925\ \text{K}^{-1}$. R_2 and R_3 are equal to $25\ \Omega$. The value of R_1 required to balance the bridge is $37.36\ \Omega$. Find the temperature of the RTD. Assume $0\ ^\circ\text{C} = 273\ \text{K}$, if necessary.



4 Points

Question 6: Displacement (10 Points)



2 Points

Q6.2 The magnetic encoding strip provides 4 pulses per revolution for each of the 2 hall effect sensors 90° out of phase. Determine the rotational displacement resolution in degrees.

2 Points

Q6.3 Assuming you have a quadrature encoder with a resolution of 20° which starts at the beginning of State 2 shown in the diagram above (Ch A = HIGH, Ch B = LOW), and does not change direction while rotating. 21 and 20 state changes (HIGH→LOW or LOW→HIGH) are counted on Ch A and B, respectively. Determine the rotational displacement in degrees, and the direction (CW = positive).

2 Points

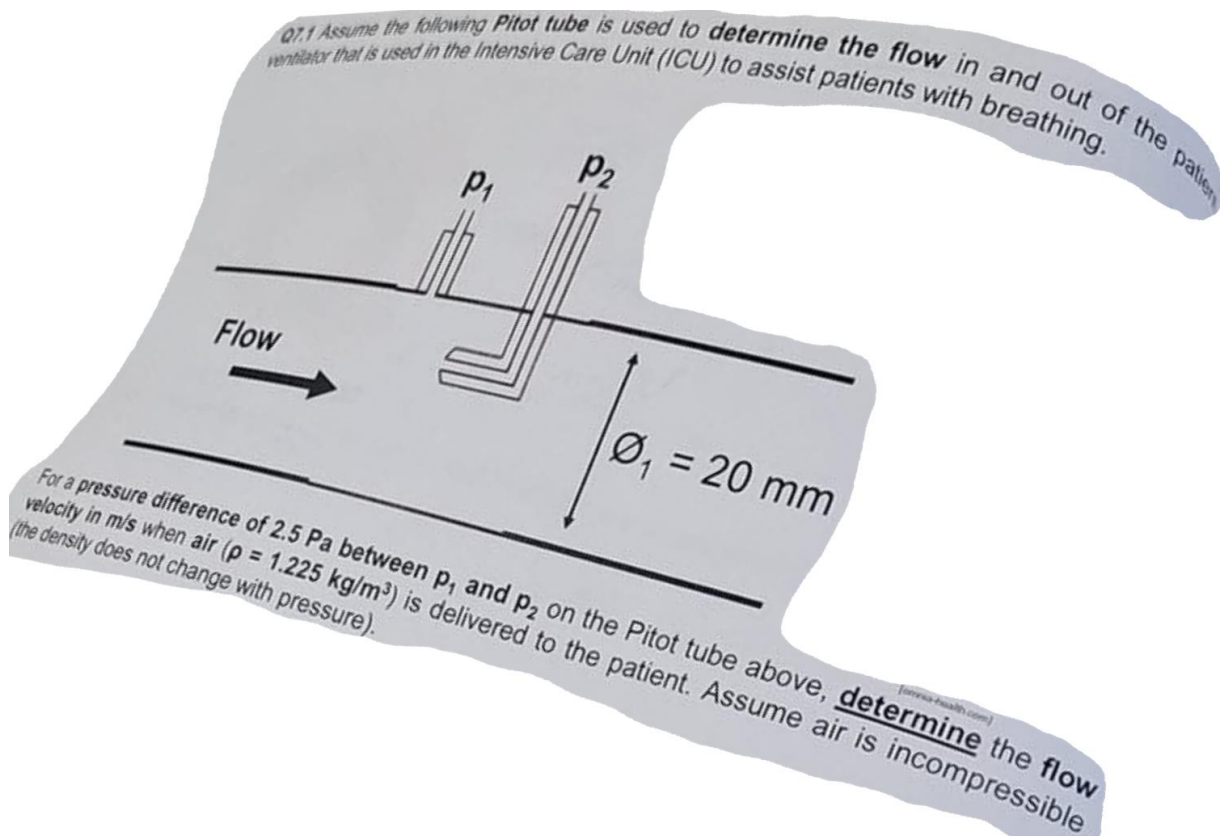
Q6.4 Now you also want to determine the maximum rotational velocity of the elbow joint. For a defined arm movement, the number of pulses that you counted for a time duration of 0.1 s corresponds to a rotational displacement of 120°. What is the maximum rotational velocity in revolutions per minute (rpm)?

2 Points

Q6.5 A fellow student suggests to measure the time needed to register a certain number of pulses instead of counting the pulses for a certain time duration. Briefly describe 2 problems that could occur by using this method.

2 Points

Question 7: Flow (14 Points)

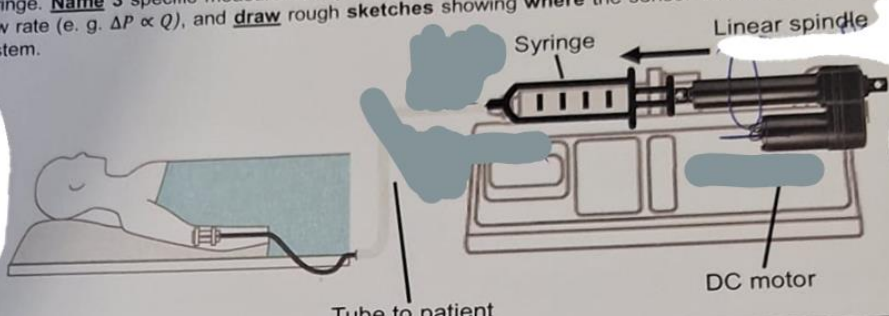


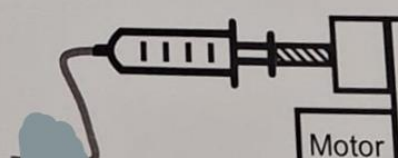
3 Points

Q7.2 Assuming a volumetric flow rate of $0.001 \text{ m}^3/\text{s}$ is achieved at $\varnothing_1$, **determine the flow** velocity in m/s.

2 Points

3 Think of further potential measurement methods, other than the Venturi tube, which could be used to determine the rate at which the volume of fluid is delivered (volumetric flow rate) by the syringe. Name 3 specific measurement principles and the relationship of the recorded value to the flow rate (e. g. $\Delta P \propto Q$), and draw rough sketches showing where the sensor could be placed in the system.



Method 1:	Sketch 1:
	
Method 2:	Sketch 2:
	
Method 3:	Sketch 3:
	

9 Points