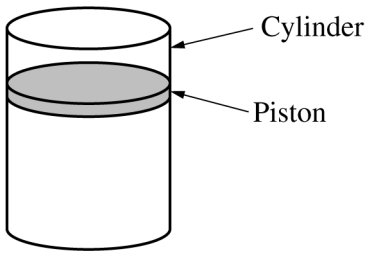
Begin your response to **QUESTION 2** on this page.



2. (12 points, suggested time 25 minutes)

A group of students design an experiment to investigate the relationship between the density and pressure of a sample of gas at a constant temperature. The gas may or may not be ideal. They will create a graph of density as a function of pressure. They have the following materials and equipment.

- A sample of the gas of known mass M_g in a sealed, clear, cylindrical container, as shown above, with a movable piston of known mass m_p
- A collection of objects each of known mass m_o
- A meterstick

(a)

i. Describe the measurements the students should take and a procedure they could use to collect the data needed to create the graph. Specifically indicate how the students could keep the temperature constant. Include enough detail that another student could follow the procedure and obtain similar data.

ii. Determine an expression for the absolute pressure of the gas in terms of measured quantities, given quantities, and physical constants, as appropriate. Define any symbols used that are not already defined.

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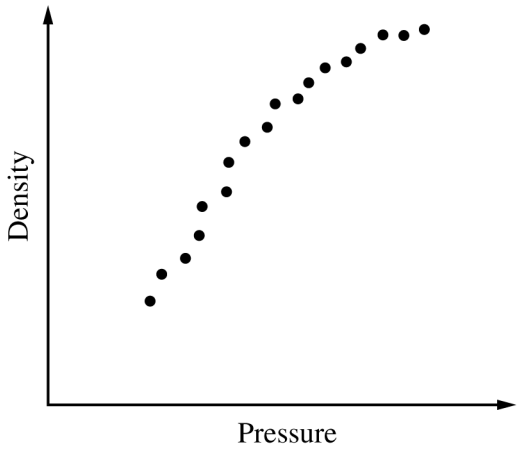
Continue your response to **QUESTION 2** on this page.

iii. Determine an expression for the density of the gas in terms of measured quantities, given quantities, and physical constants, as appropriate. Define any symbols used that are not already defined.



iv. The graph above represents the students' data. Does the data indicate that the gas is ideal? Describe the application of physics principles in an analysis of the graph that can be used to arrive at your answer.

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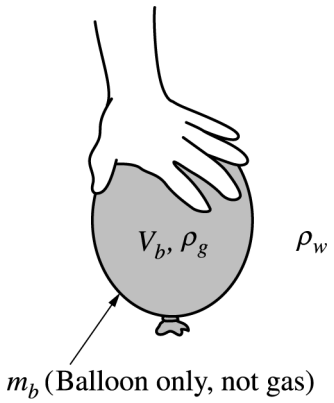
Continue your response to **QUESTION 2** on this page.

Another group of students propose that the relationship between density and pressure could also be obtained by filling a balloon with the gas and submerging it to increasing depths in a deep pool of water.

(b) Why could submerging the balloon to increasing depths be useful for determining the relationship between the density and pressure of the gas?



(c) The balloon is kept underwater in the deep pool by a student pushing down on the balloon, as shown above. Let V_b represent the volume of the inflated balloon, m_b represent the mass of just the balloon (not including the mass of the gas), ρ_g represent the density of the gas in the balloon, and ρ_w represent the density of the water. Derive an expression for the force the student must exert to hold the balloon at rest under the water, in terms of the quantities given in this part and physical constants, as appropriate.

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Question 2: Experimental Design — 12 points

(a)	**i.**	For describing a valid method for keeping the temperature constant	**1 point**
		For describing a valid use of the objects of known mass to affect the pressure	**1 point**
		For explicitly measuring the height h and the radius r (or diameter) of the piston	**1 point**
		For explicitly obtaining more than two data points	**1 point**
		Example response for part (a)(i) *Place the container in an ice bath, so the part below the piston is submerged. Measure the radius and height of the piston. For eight different objects of known mass, add each object on the piston and measure the height of the piston for each object.*	
	ii.	For an equation that correctly relates pressure to measured quantities consistent with the procedure in (a)(i)	**1 point**
		Example response for part (a)(ii) $P_{tot} = P_{atm} + \left(m_p + Nm_o\right)g/A = P_{atm} + \left(m_p + Nm_o\right)g/\left(\pi r^2\right)$, *where N is the number of objects on the piston and r is the radius of the piston.*	
	iii.	For an equation that correctly relates the density of the gas to measured quantities	**1 point**
		Example response for part (a)(iii) $\rho = M_g/V = M_g/\left(\pi r^2 h\right)$	
	iv.	For referring to the ideal gas law or Boyle's Law and using the equation to show pressure and volume are inversely proportional	**1 point**
		For a conclusion based on an analysis of the slope of the graph and a correct relationship between pressure and density	**1 point**
		Example response for part (a)(iv) *According to the ideal gas law, pressure is proportional to 1/V. Because the mass of this gas is constant, pressure is, therefore, directly proportional to density. The graph does not show a linear relationship between density and pressure, so the gas is not ideal.*	
		Total for part (a)	**8 points**
(b)		For indicating that the water pressure, and thus the pressure on the balloon and of the gas, increases as the depth is increased	**1 point**
		Example response for part (b) *When the balloon goes deeper in the fluid, the pressure increases. This will cause the volume of the balloon to decrease.*	

(c)	For correctly applying Newton's second law with some specific elements of the problem, including one of the two weights	**1 point**
	For a correct expression for the weight of the balloon and gas	**1 point**
	For a correct expression for the buoyant force	**1 point**
	Example response for part (c) $\sum F = 0 = F_B - W_{\text{balloon}} - W_{\text{gas}} - F_{\text{student}}$ $F_B = \rho_w V_b g$ $W = \rho_g V_b g + m_b g$ $F_{\text{student}} = \rho_w V_b g - \left(\rho_g V_b g + m_b g\right)$	
	Total for part (c)	**3 points**
	Total for question 2	**12 points**