AUSTRALIAN SCIENCE INNOVATIONS

Australian Science Olympiads

2019 AUSTRALIAN SCIENCE OLYMPIAD EXAM

PHYSICS

Time Allowed

Reading Time: 10 minutes

INSTRUCTIONS

- ***Attempt all questions in ALL sections of this paper.***
- **Permitted materials: non-programmable, non-graphical calculator, pens, pencils, erasers and a ruler.**
- **Answer Section A on the MULTIPLE CHOICE ANSWER SHEET PROVIDED. Use a pencil.**
- **Answer Section B in the Answer Booklet provided. Write your answers to each question on the pages indicated. For extra space, use the final pages of the booklet. Write in pen and use pencil only for diagrams and graphs.**
- **Do not write on this question paper. It will not be marked.**
- **Do not staple the Answer Sheet or Answer Booklet.**
- **Marks will not be deducted for incorrect answers.**
- **Ensure your diagrams are clear and labelled.**
- **All numerical answers must have correct units.**

Examination Time: 120 minutes

MARKS

Section A	**10 multiple choice questions**	**10 marks**
Section B	**4 written answer questions**	**45 marks**
TOTAL		**55 marks**

Integrity of Competition

If there is evidence of collusion or other academic dishonesty, students will be disqualified. Markers' decisions are final.

SECTION A: MULTIPLE CHOICE
USE THE ANSWER SHEET PROVIDED

Question 1

A box of mass 5 kg sits at rest on a horizontal floor. What is the Newton's third law (reaction) force to the normal force of the floor on the box (action)?

a. The weight of the box.
b. The normal force of the box on the floor.
c. The gravitational force of the Earth on the box.
d. The gravitational force of the box on the Earth.
e. There is no reaction force in this situation.

Question 2

A box of mass 5 kg sits at rest on a horizontal floor. A vertically upwards force of 20 N is exerted on the box by someone trying to lift it. What is the magnitude of the normal force exerted by the floor on the box while the 20N upwards force is being exerted?

a. 0 N (the box is no longer in contact with the floor)
b. 20N
c. 30N
d. 50N
e. 70N

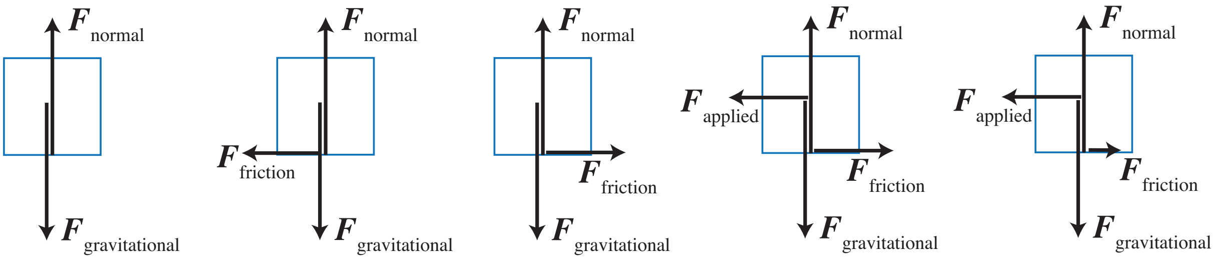
Question 3

An elevator is moving upwards with constant upwards acceleration. At some point in the elevator's motion, a bolt breaks loose and drops from the ceiling. What is the motion of the bolt as seen by an observer standing inside the elevator? Ignore air resistance.

a. The bolt immediately moves downwards, at constant speed.
b. The bolt initially moves upwards, then slows, reverses direction and moves downwards.
c. The bolt immediately moves downwards, with acceleration less than g.
d. The bolt immediately moves downwards, with acceleration equal to g.
e. The bolt immediately moves downwards, with acceleration greater than g.

Question 4

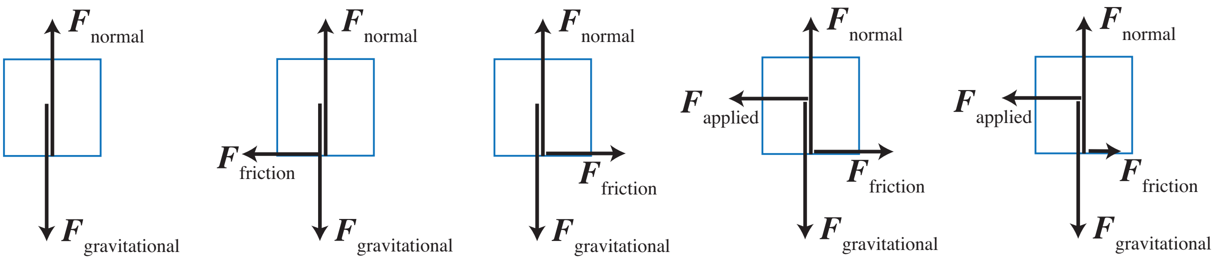
Trish is moving boxes of photocopy paper on a trolley. The top of the trolley is flat, and a box sits on it as shown. Trish pushes the trolley, accelerating it to the left, as shown. Which of the following diagrams correctly shows the forces acting on the box as it is accelerating to the left? The length of the force arrows is proportional to the size of the force. Ignore air resistance.



a. b. c. d. e.

Question 5

Once the trolley is at the desired speed, Trish keeps it at that constant speed. Which of the following diagrams correctly shows the forces acting on the box as it moves at constant speed to the left? The length of the force arrows is proportional to the size of the force. Ignore air resistance.



a. b. c. d. e.

Question 6

Ali and Beatrice are doing an experiment to measure the spring constant, k, of a spring. The spring constant is a measure of how stiff or stretchy a spring is. Ali is going to use a static method, using the equation $k = \frac{F_{\text{applied}}}{s} = \frac{mg}{s}$, where m is the mass of a weight attached to the hanging spring, and s is the distance that the spring stretches by.
Which method will give Ali the most accurate and precise result for k?

a. Hang one weight on the spring, and measure how far the spring stretches. Put this pair of values into the equation.

b. Hang two different weights on the spring (one at a time), and measure how far each weight stretches the spring. Put these two pairs of values into the equation and average the results.

c. Hang at least three different weights on the spring (one at a time), and measure how far each weight stretches the spring. Put these pairs of values into the equation and average the results.

d. Hang at least three different weights on the spring (one at a time), and measure how far each weight stretches the spring. Plot a graph of m vs s and find the value of k from the gradient of a line of best fit for the data.

e. Hang at least three different weights on the spring (one at a time), and measure how far each weight stretches the spring. Plot a graph of m vs s and find the value of k from the gradient of a line of best fit to the data that also passes through the origin.

Question 7

Ali has spent too much time deciding what to do, and only takes one pair of measurements. He measures the mass of the weight to be (100 ± 5) g and the stretch, s, when he hangs it on the spring to be (5.0 ± 0.5) cm. Based on these data, the spring constant is:

a. (20.0 ± 0.2) N/m

b. (20 ± 3) N/m

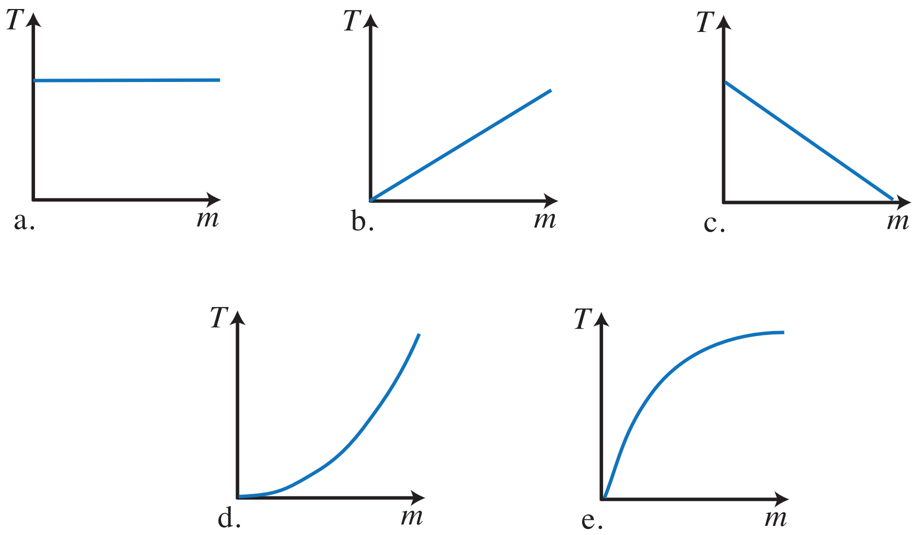
c. (20 ± 6) N/m

d. (200 ± 20) N/m

e. (200 ± 30) N/m

Question 8

Beatrice has decided to use a dynamic method to find k for her spring. She measures the period, T, of oscillation for a mass, m, on a spring for a series of different masses. The equation that relates period to mass is: $T = 2\pi\sqrt{\frac{m}{k}}$. If Beatrice plots a graph of T vs m, which of the following graphs will her plot look like?



Question 9

Beatrice wants to plot a straight line graph and find the value of k from the gradient of the graph. To do this, she should:

a. Plot T vs m, and then the gradient is $\frac{1}{k}$.

b. Plot T vs m, and then the gradient is $\frac{2\pi}{\sqrt{k}}$.

c. Plot T^2 vs m, and then the gradient is $\frac{2\pi}{\sqrt{k}}$.

d. Plot T^2 vs m, and then the gradient is $\frac{2\pi}{k}$.

e. Plot T^2 vs m, and then the gradient is $\frac{4\pi^2}{k}$.

Question 10

An elevator is moving upwards a constant speed. Ignoring any friction, which statement is correct?

a. The kinetic energy of the elevator is constant.

b. The gravitational potential energy of the Earth-Elevator system is constant.

c. The mechanical energy of the Earth-Elevator system is constant.

d. a and c are both correct, but b is not correct.

e. a, b and c are all correct.

SECTION B: WRITTEN ANSWER QUESTIONS
USE THE ANSWER BOOKLET PROVIDED

Throughout, take the acceleration due to gravity to be $9.8\ \mathrm{m\,s^{-2}}$.

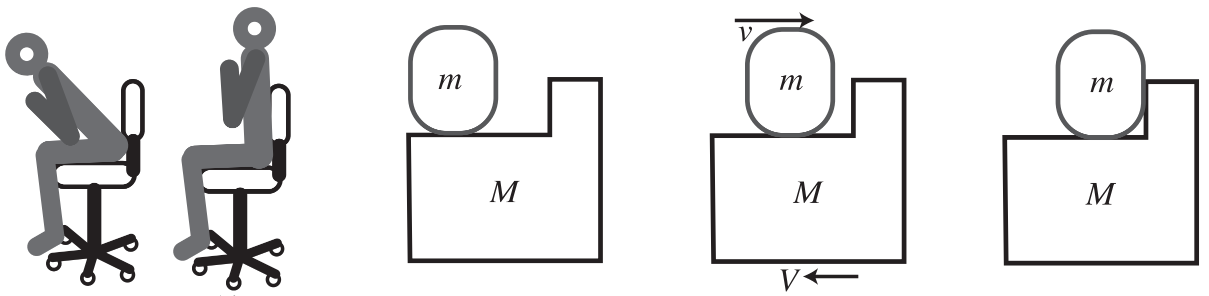
Question 11

Zara and Jackie are excited about their new desk chairs. Zara plans to sit and do physics in comfort. Jackie plans to move around on a chair without touching the ground or anything else. “But that’s physically impossible!”, says Zara. Jackie replies, “No! I’ve done it before. I lean forward really slowly, and then lean back as fast as I can.” Jackie shows Zara how to do it, and she wants to understand it.

Zara calls Jackie’s body from the waist up Object 1, and Jackie’s legs, from the waist down, and the chair combined Object 2. Zara models the fast part of Jackie’s motion using the principle of conservation of momentum. In other words, she thinks that the total momentum of Jackie and the chair (Object 1 + Object 2) remains unchanged while Jackie leans backwards. (Hint: momentum $p = mv$)

Zara identifies three important times in her model

- t_1 when Jackie is stationary just before leaning back,
- t_2 when Jackie is in the process of leaning back, and
- t_3 when Jackie’s back hits the back of the chair.



Jackie at t_1 Jackie at t_3 Zara’s model at t_1 Zara’s model at t_2 Zara’s model at t_3

Object	Mass	momentum at t_1	velocity at t_2	velocity after t_3	displacement from t_1 to t_3
1	$m = 25$ kg	$p_{m1} =$	$v_{m2} = -0.5\ \mathrm{m\,s^{-1}}$	$v_{m3} =$	$s_m = -30$ cm
2	$M = 35$ kg	$p_{M1} =$	$v_{M2} =$	$v_{M3} =$	$s_M =$
1+2	$m + M =$	$p_{\text{tot1}} =$	$v_{\text{cm2}} =$	$v_{\text{cm3}} =$	$s_{\text{cm}} =$

s_{cm} is the position of the centre of mass, which is the average position of all the mass, and v_{cm2} and v_{cm3} are the velocities of this point at times t_2 and t_3 respectively.

a) (i) By applying the principle of conservation of momentum, complete the copy of the table above which is on p. 2 of the Answer Booklet. Show your reasoning below the table.

(ii) Explain why, in Zara’s model, the position of the centre of mass of Jackie and the chair never changes, regardless of how far or fast Jackie moves.

b) (i) Describe the motion of Objects 1 and 2 as Jackie leans forward very slowly.

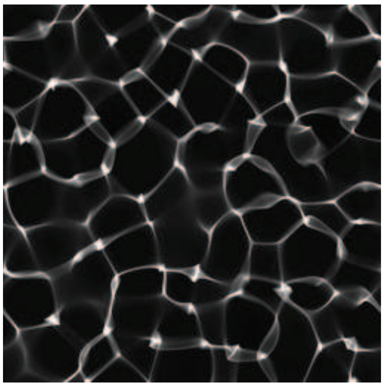
(ii) Give an explanation of Jackie's motion while leaning very slowly, using ideas from physics.

c) Identify any additional physical effects Zara should include in her model and how these affect the predicted motion. If there are none, state effects you considered and why they may be neglected.

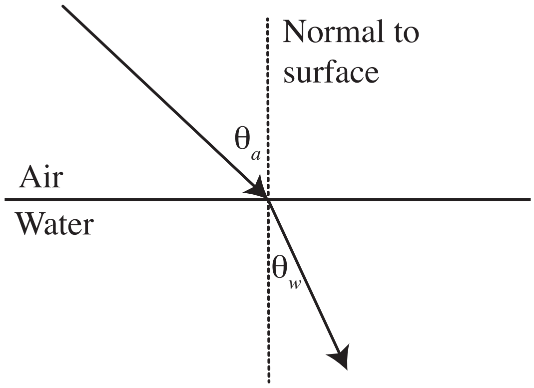
d) Sketch the positions of Object 1, Object 2, and also the centre of mass position of Jackie and the chair through one cycle of leaning forward very slowly and then leaning back rapidly. Use the axes on p. 3 of the Answer Booklet.

Question 12

Daphne the Diving Bell Spider is on an excursion to the surface of her pool in the forest. The water of the pool is very clear. Sitting high on a rock on a sunny morning, Daphne can observe many bright lines separated by darker regions moving around the flat bottom of the pool. The bright lines, shown below, are known as *caustics* and can be explained by the refraction of light rays at the irregular surface of the pool. When a light ray travels from air into water it refracts, bending so that the angle between the ray and a line perpendicular to the surface (called the *normal*) is smaller in the water.



Caustics at the bottom of the pool

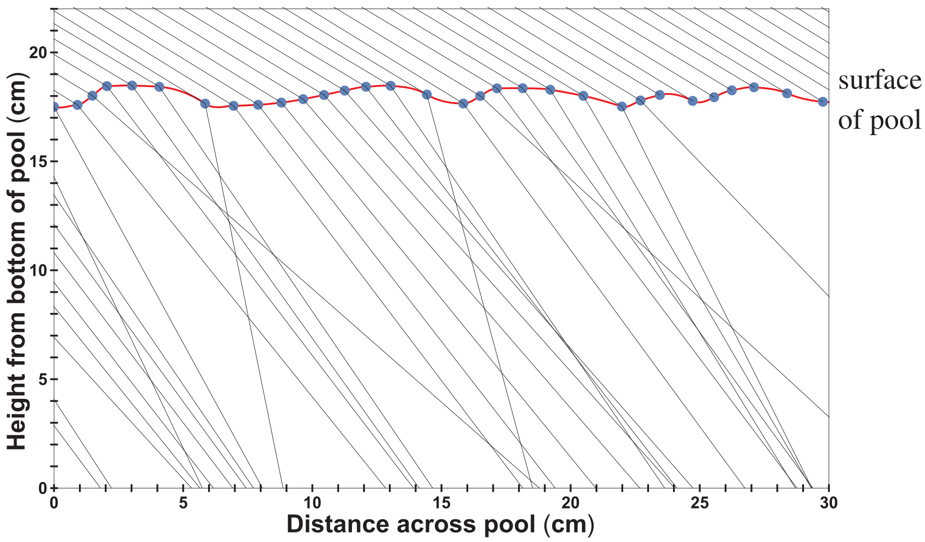


Light refracting at an air-water interface.

a) A 'slice' of the forest pool at one instant is shown below. A series of parallel light rays is shown being refracted at the uneven surface of the pool.

(i) Complete the diagram by drawing in the missing rays on p. 4 of the Answer Booklet.

(ii) Sketch the intensity of the light on the bottom of the pool. Use the axes supplied on p. 4 of the Answer Booklet.



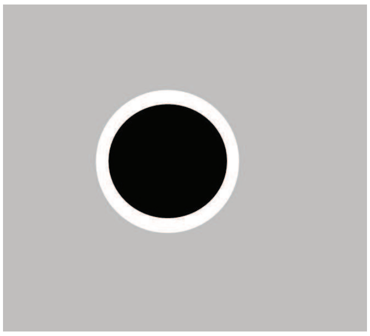
At midday with the sun directly above the pool, Daphne ventures out onto the now calm, flat surface of the pool. While near the shallow edge of the pool, where the bottom is flat, she asks her mate Mavis the moth to fly overhead and observe. Mavis reports that Daphne's shadow on the bottom of the pool is very large.

b) Based on this observation, select whether Daphne makes either Profile 1 or Profile 2 when she is on the surface of the pool, and explain your choice using words and diagrams. Both surface profiles are drawn on p. 4 of the Answer Booklet for you to use.

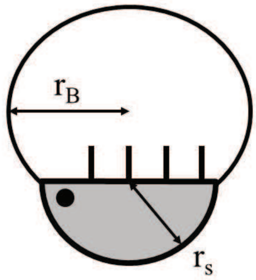
Profile 1

Profile 2

c) Mavis can also see a bright ring around Daphne's shadow on the bottom of the puddle. A schematic diagram of the brightly-rimmed shadow is shown to the right. Explain the origin of this bright ring.



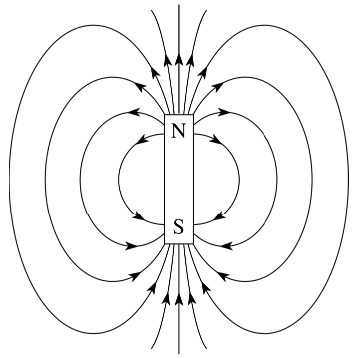
Daphne decides to dive back to the bottom of the pool, taking a bubble of air with her. Archimedes' Principle states that the buoyant force on an object is equal to the weight of the volume of fluid displaced by that object. Daphne's bubble can be modelled as 0.9 of a sphere with radius r_B and no mass, while Daphne is hemispherical in shape with a radius r_s and mass m_s (see right). The water has density ρ.



d) Find the largest r_B such that Daphne can sink to the bottom of the pool.

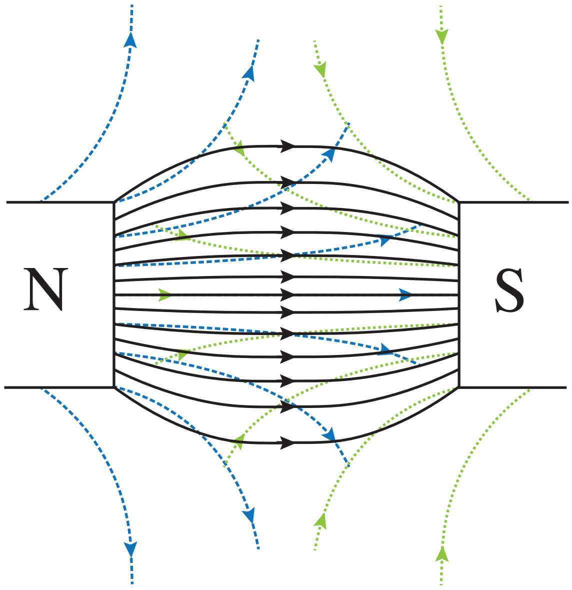
Question 13

Maggie has two identical fridge magnets. The magnetism of the fridge magnets can be thought of as due to many tiny bar magnets. A bar magnet has a north pole and a south pole, and magnetic field surrounding it as shown to the right. Field lines closer together indicate a stronger magnetic field, while the arrows indicate the direction of the magnetic field. Like poles repel, and opposite poles attract.



The magnetic field of two magnets is the *superposition* of the individual magnets, becoming stronger where the two contributions are in the same direction and weaker where they are in opposite directions.

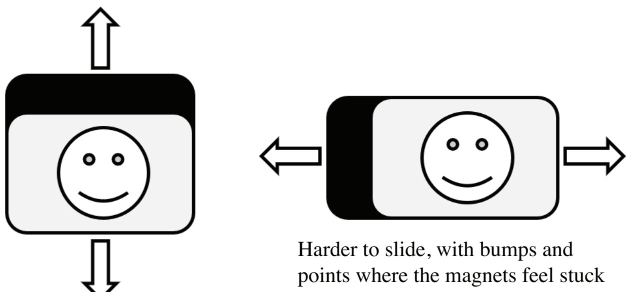
a) Apply the principle of superposition to sketch magnetic field line diagrams for the two arrangements of bar magnets shown on p. 6 of the Answer Booklet.



Maggie's fridge magnets will only stick to the fridge on one side – the black side – and the two fridge magnets stick to each other most strongly when the black sides are touching. They won't stick to each other at all if the two picture sides are touching. This leads Maggie to believe that on the black side of a fridge magnet the magnetic field is very strong, and on the other side it is very weak.

b) Show how bar magnets could be arranged to make a very strong field on one side, and a weak field on the other. You do not need to include a full magnetic field line diagram with your arrangement, but you should indicate where superposition of the fields results in a stronger or weaker field, and the approximate direction of the field.

When Maggie's two fridge magnets are stuck together with their black sides touching, they are more easily slid apart vertically compared to horizontally. Maggie also notices that sliding apart in the horizontal direction feels bumpy, with the magnets alternating between slightly attracting and repelling each other.

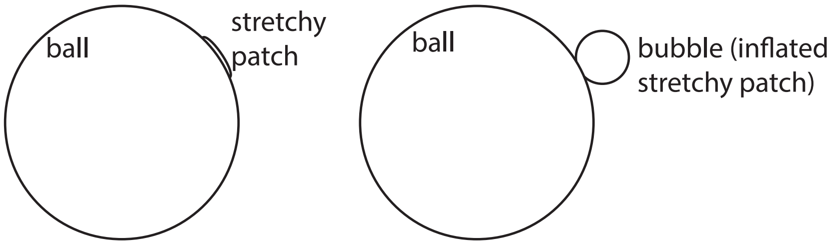


c) On the diagram on p. 7 of the Answer Booklet, draw how small bar magnets might be arranged, either as a grid, rows or columns, in one of Maggie's fridge magnets. You may use as many, or as few, of the diagrams as you need to describe the arrangement. You may draw the bar magnets as arrows to simplify your diagrams.

Question 14

Air applies a force due to its *pressure* uniformly across any surface it contacts. A stretching wall requires a certain amount of force to expand, and applies a force on the air inside, increasing the inside pressure needed to keep the air contained. This is why a balloon stretches and if you untie it, the air is pushed out.

A large firm ball is full of air. The ball has a small bubble made of a stretching wall attached to it that starts out empty.



Someone squeezes the ball such that they apply a steadily increasing additional pressure to the ball and hence the air inside it. After a short time the bubble begins to inflate. Once it starts inflating, it rapidly increases in size. The firm ball's size hardly changes throughout.

a) (i) Sketch the pressure inside the ball versus time since the squeezing began.
   (ii) Sketch, roughly, the volume of the bubble versus time since the squeezing began.
   (iii) Sketch, roughly, the force applied per area of the small bubble versus its volume.
   (iv) Sketch, roughly, the force applied per area of the small bubble versus the amount of gas in the small bubble.

b) If instead of squeezing the ball, it is heated at a constant rate, explain whether or not you would expect your sketches to change. You might find the following relationship between temperature T, pressure p and volume V for an ideal gas to be useful: $pV = AT$ where A is a constant depending only on the amount of gas. A is directly proportional to the amount of gas.

A group of students are given the challenge of designing an experiment to measure the change in the force per area applied by the stretchy wall as a function of its size. They have at their disposal a range of common objects, including heaters, scales, air pumps, and basic measuring tools, but do not have a large budget or any purpose-built lab spaces.

c) Design an experiment to perform that the students could use. Include what you would need to measure and how.

d) For your design, where do you think the most likely sources of uncertainty in your results will come from? Remember to think about all parts of the experiment, not just the resolution of your instruments.

Integrity of Competition

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