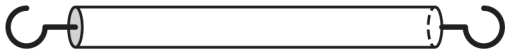
Begin your response to **QUESTION 2** on this page.



2. (12 points, suggested time 25 minutes)

A group of students is investigating how the thickness of a plastic rod affects the maximum force F_{max} with which the rod can be pulled without breaking. Two students are discussing models to represent how F_{max} depends on rod thickness.
Student A claims that F_{max} is directly proportional to the radius of the rod.
Student B claims that F_{max} is directly proportional to the cross-sectional area of the rod—the area of the base of the cylinder, shaded gray in the figure above.

(a) The students have a collection of many rods of the same material. The rods are all the same length but come in a range of six different thicknesses. Design an experimental procedure to determine which student's model, if either, correctly represents how F_{max} depends on rod thickness.

In the table below, list the quantities that would be measured in your experiment. Define a symbol to represent each quantity, and also list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

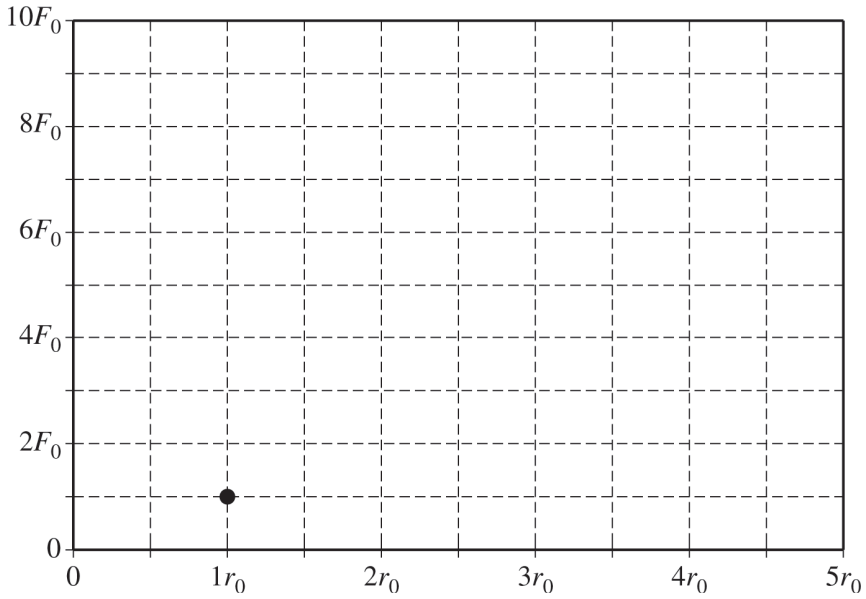
Quantity to be Measured	Symbol for Quantity	Equipment for Measurement

GO ON TO THE NEXT PAGE.

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

Describe the overall procedure to be used, referring to the table. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table and/or include a simple diagram of the setup.

(b) For a rod of radius r_0, it is determined that F_{max} is F_0, as indicated by the dot on the grid below. On the grid, draw and label graphs corresponding to the two students' models of the dependence of F_{max} on rod radius. Clearly label each graph "A" or "B," corresponding to the appropriate model.



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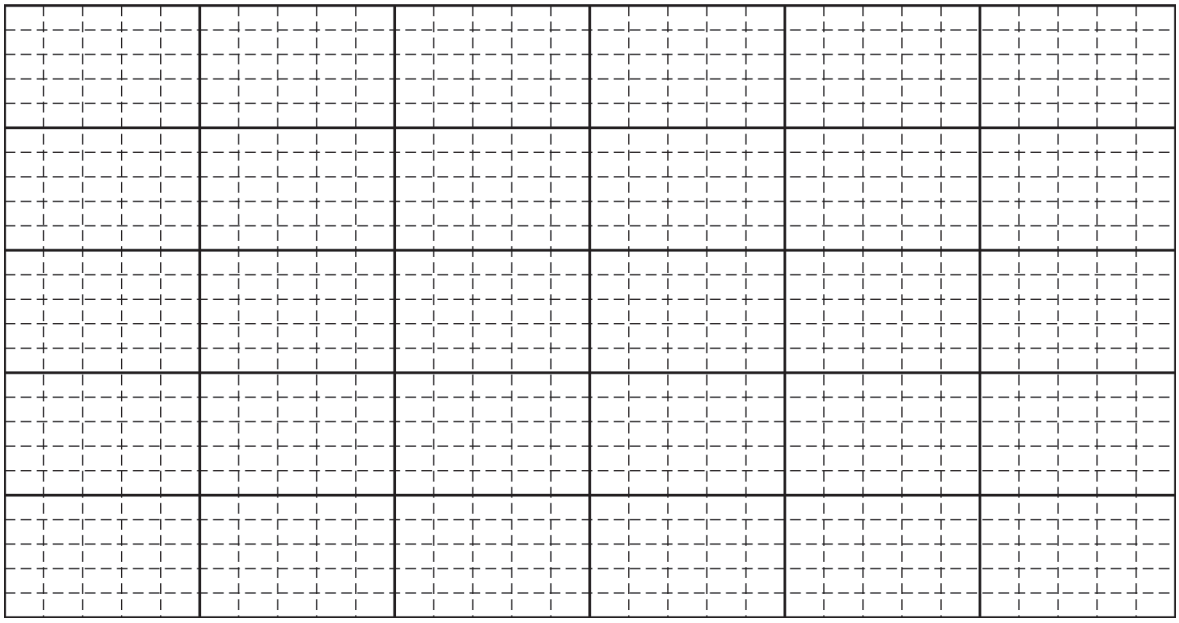
Continue your response to **QUESTION 2** on this page.

The table below shows results of measurements taken by another group of students for rods of different thicknesses.

Rod radius (mm)	0.5	1.0	1.5	2.0	2.5
F_{max} (N)	40	120	320	520	900

(c) On the grid below, plot the data points from the table. Clearly scale and label all axes, including units. Draw either a straight line or a curve that best represents the data.



(d) Which student's model is more closely represented by the evidence shown in the graph you drew in part (c) ?

____ Student A's model: F_{max} is directly proportional to the radius of the rod.

____ Student B's model: F_{max} is directly proportional to the cross-sectional area of the rod.

Explain your reasoning.

GO ON TO THE NEXT PAGE.

Question 2: Experimental Design — 12 points

(a)

For measuring the radius or diameter of rods with different radii using an appropriate tool	**1 point**
For measuring force using an appropriate tool	**1 point**
For a plausible/practical way to directly or indirectly determine F_{max} for a given rod	**1 point**
For attempting to reduce experimental uncertainty in an experiment that involves breaking the rods	**1 point**

Example response for part (a)

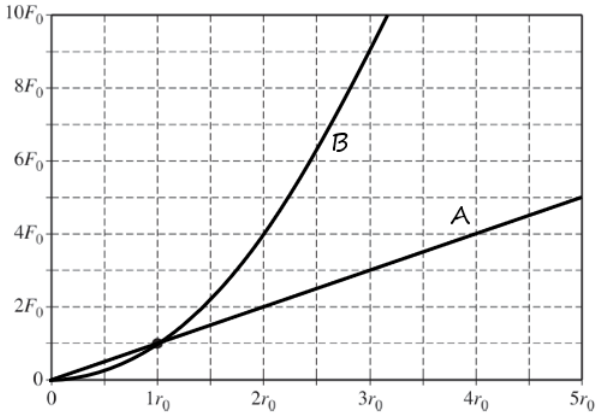
Measure the diameter D of each rod with a ruler.
Students should pull on the rod with the force probe until the rod breaks.
Record the force F_{max} just before breaking.
Repeat each trial several times to reduce error.
Then trade for a new set of rods with different radii.
Repeat this experiment for several different radii rods.

Total for part (a) **4 points**

(b)

For a straight-line graph marked "A" with a slope of $\frac{F_0}{r_0}$	**1 point**
For a graph marked "B" that is concave up	**1 point**
For a graph marked "B" that shows a quadratic relationship at the correct points	**1 point**
For two graphs that both contain the point (r_0, F_0)	**1 point**

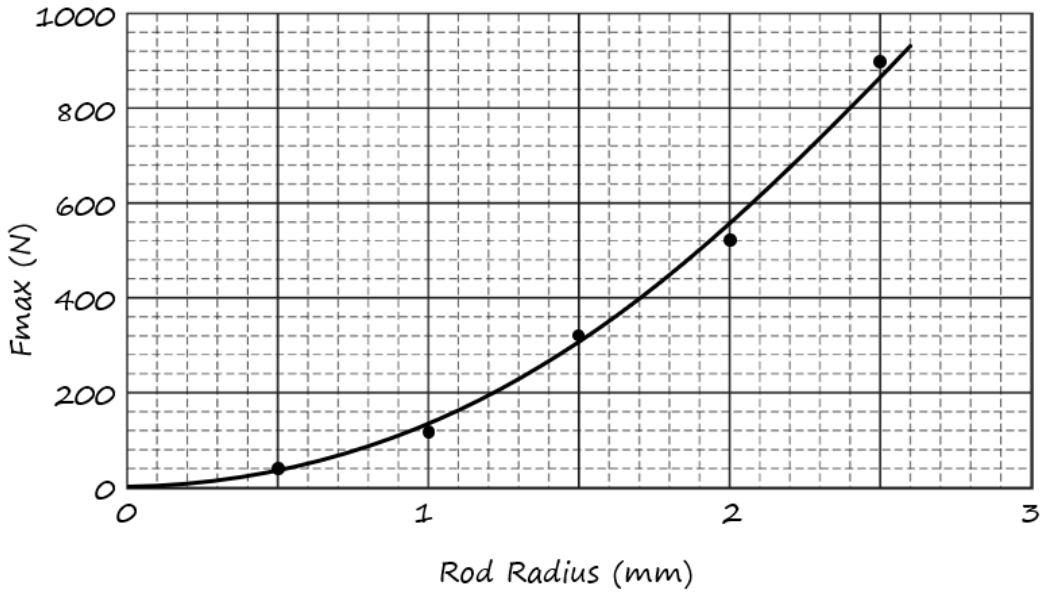
Example response for part (b)



Total for part (b) **4 points**

(c)	For linear scales with appropriate labels and units **AND** for a graph where the plotted points cover at least half of the grid's width and height	**1 point**
	For plotting the points correctly	**1 point**
	For drawing a reasonable best-fit curve	**1 point**

Example response for part (c)



Total for part (c) **3 points**

(d)	For identifying Model B and for indicating that F_{max} increases as the square of the radius increases	**1 point**

Example response for part (d)

In this graph, F_{max} seems to be proportional to R^2, so that if we graph F_{max} on the vertical axis and R^2 on the horizontal axis, it should show a linear graph.

Total for question 2 **12 points**