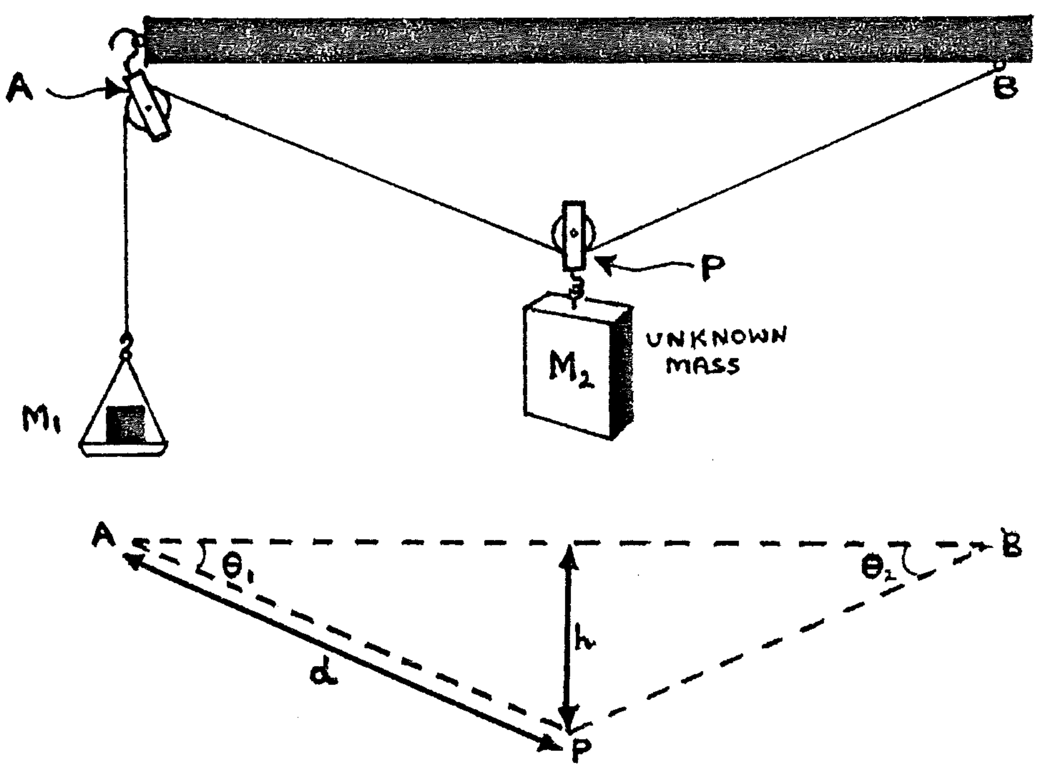
B1-2: Tension in a String: Find an Unknown Mass Using Equilibrium of Forces Theory.

Apparatus



Wooden rod about 1m long with eyelets as shown; about 1.7m good-quality cord; 2 single pulleys; 2 x 50g masses; 5 x 100g masses; scale pan; unknown mass; 2 clamps & stands; 2 G-clamps; triple beam balance; metre ruler; 1 sheet graph paper; spirit level.

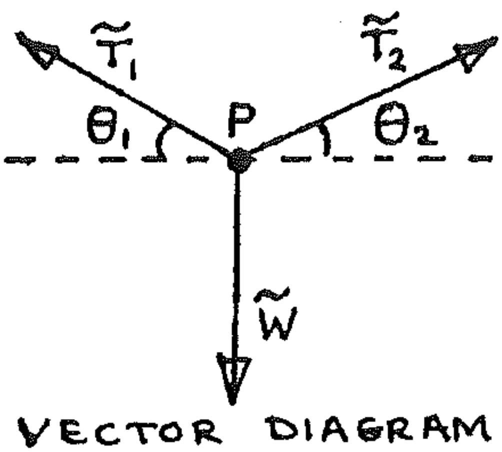
Procedure

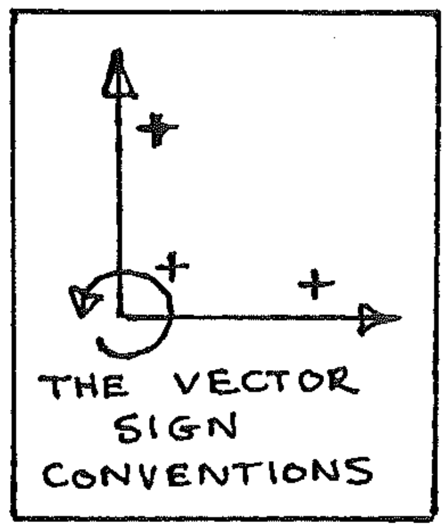
1. Clamp the wooden rod firmly and horizontally, so that there is space for the scale

pan and unknown mass to move a large distance vertically without touching any object. Assemble the apparatus as above, placing m = 200g in the scale pan. Measure and record AB.

2. Move m_1 up and down, finally placing it in the middle of the range of possible equilibrium positions. Ensure that pulley P is directly under the mid-way mark on the rod. Measure and record values of m_1 , h, and d.
3. Repeat 2. with m_1 = 250g, 300g, 350g, 400g, 500g, 600g, each time recording m_1, h, and d. Check that the pulley P remains under the mid-way mark on the rod.

Theory





Since point P is in equilibrium (Newton's 1st law):

$$\text{Resultant } \tilde{R} = \tilde{T}_1 + \tilde{T}_2 + \tilde{W} = \tilde{0}$$

Therefore **horizontally**:

$$\sum F_x = 0 \quad \therefore \quad T_2\cos\theta_2 - T_1\cos\theta_1 = 0$$

However, $\theta_1 = \theta_2$ (observation), therefore:

$$T_1 = T_2$$

And **vertically**:

$$\sum F_y = 0 \quad \therefore \quad T_1 \sin\theta_1 + T_2 \sin\theta_2 - W = 0$$

but $\theta_1 = \theta_2$ and $T_1 = T_2$, so:

$$2T_1 \sin\theta_1 - W = 0 \qquad \textbf{---- equation 1}$$

but $T_1 = m_1 g$, $\sin\theta_1 = \frac{h}{d}$, and $W = m_2 g$, hence:

$$\frac{h}{d} = \frac{m_2}{2m_1}$$

Analysis

1. Plot a graph of $\frac{h}{d}$ against $\frac{1}{m_1}$, and find the gradient.
2. Use only the gradient and the formula given at the end of the theory to calculate the unknown mass m_2.
3. Measure the mass of m_2: on the beam balance, and assuming this is accurate, calculate the % error in the value obtained in 2. above.
4. a. Use the value of $\frac{h}{d}$ when $m_1 = 400g$, to calculate θ_1 at this point. Calculate $W = m_2 g$.

   b. m_1 is suddenly increased to $500g$.

   Assuming that at this moment $\theta_1 = \theta_2 = \text{the value from a.}$, find the initial upward acceleration of m_2, as it heads towards a new equilibrium position.

   (Hint: find T_1 and use part of **equation 1** to find the net upward force on m_2 .)