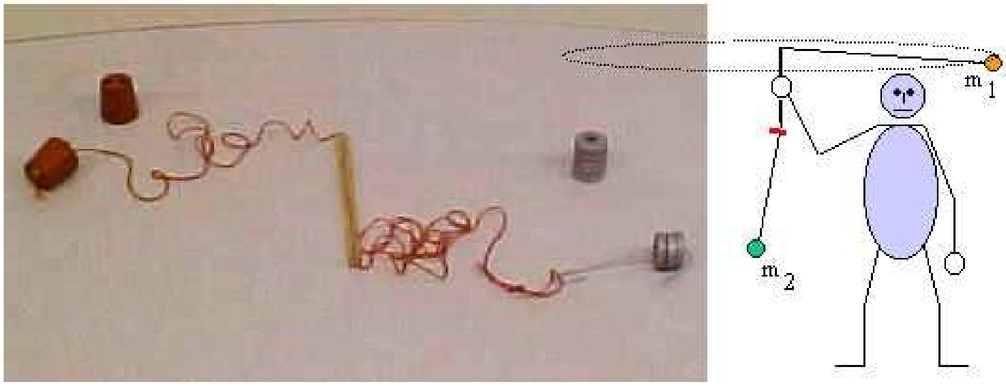
Gauss's law

Title: Going round in circles

Aim: To see/feel centripetal force.

Subjects: 1D50 (Central Forces)

Diagram:



Equipment:

- Tube, with rounded edges, l=15cm.
- Piece of rope, l=1.5m.
- Two rubber stoppers (m_1).
- A number of weights (m_2). We use thick washers.
- Paperclip.
- (Stopwatch).

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Presentation: Diagram shows the components and how to use them. Swinging the tube a little makes the mass m_1 go round in circles above your head. The demonstrator needs to make m_1 go round at a certain frequency to balance the system.

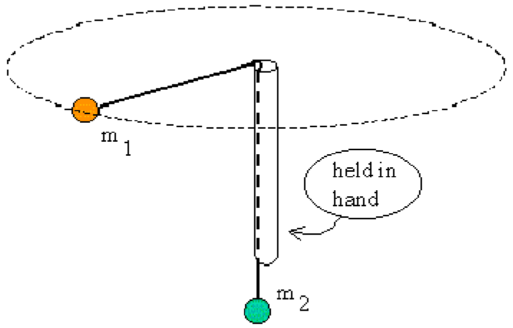

Figure 1

- When he slows down to a lower frequency m_2 will move down, making the circle of m_1 smaller and smaller. Speeding up makes m_2 go upward and m_1 goes round in larger and larger circles.
- The demonstrator makes m_1 go round in a stable circle. Then he grabs m_2 and pulls it downwards. m_1 speeds up dramatically, going round in smaller and smaller circles.

If time permits the relationship between the variables in this demonstration can be verified more exactly.
Just below the tubing a paperclip is fixed to the rope used as a marker to make m_1 go round in a circle with fixed R. A stopwatch can be used to time the frequency.

1. When m_1 is doubled by adding another rubber stopper to it, a lower frequency is needed to balance the system.
2. When m_2 is increased, a higher frequency is needed to balance the system.
3. When half the rope length is used (shifting the paperclip) a higher frequency is needed to balance the system.

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Explanation: Analysis shows that movement at a constant speed *(v)* of a mass (m_1) in a circle with radius R can be described by $a_c = \frac{v^2}{r}\omega^2 R$. In our demonstration the tension (T) in the string provides the force needed for a_c: $T=m_1a_c$, and $m_2 g = m_1 a_c \Rightarrow a_c = \frac{m_2}{m_1} g$, (see Figure2).

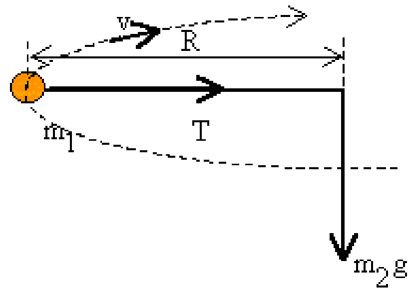

Figure 2

- First, the demonstrator showed a balanced situation. Then he slowed down ω. The centripetal acceleration, describing such a slower movement, will be lower ($a_c=\omega^2 R$). But T is a fixed value, so T will pull m_1 inwardly. As $a_c=\omega^2 R$ shows, this proces is cumulative and m_1 ends at the centre of the circle.
- When m_2 is pulled downwards, the stringtension increases substantially and so a_c will. According to $a_c=\omega^2 R$ and seeing that R decreases, ω increases much.

1. Doubling m_1 means that the provided a_c by the tension of the string will be halved ($a_c = \frac{m_2}{m_1} g$). To make m_1 still go round in the same circle ω has to be a factor $\sqrt{2}$ lower ($a_c=\omega^2 R$).
2. Increasing m_2 will make the string tension higher and so the provided a_c is higher ($T=m_1a_c$). To make m_1 still go in the same circle, ω has to increase.
3. When R is halved. Tthe tension in the string has remained the same, so the provided a_c has remained the same. To make m_1 still go in a (smaller) circle, ω has to increase a factor $\sqrt{2}$ ($a_c=\omega^2 R$).

Remarks:

- Practice the demonstration before you show it. A practiced hand is needed to make m_1 go round properly.
- We use rubber stoppers as masses moving around in circles for safety reasons.
- The spinning mass should be light compared to the hanging weight (about a factor 3), because otherwise the angle between the string and the vertical does not approach 90°: there will be more friction and due to the slanting rope (making a cone of our circle) the analysis becomes a different one.
- In the last part of the presentation (grabbing and pulling m_2 downwards) the demonstrator will feel that quite a lot of force is needed. It is of course most instructive for the students if they feel this force themselves (during coffeebreak?).

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Sources:

- Ehrlich, Robert, Turning the World Inside Out and 174 Other Simple Physics Demonstrations, pag. 72-73
- Mansfield, M and O'Sullivan, C., Understanding physics, pag. 68-71 and74-75

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