AUSTRALIA
SCIENTIFIC

SAUNDERS CIRCULAR MOTION KIT

conceived & written by
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WORKSHEET

NAME: ____________________

PARTNER: ____________________

TEACHER: ____________________

DATE: ____________________

When any object is moving in a circle at constant speed it is constantly changing direction. Hence its velocity is changing and therefore it is accelerating. This acceleration is constant in size and its direction is towards the centre of the circle. It is called the centripetal acceleration. The resultant force acting on an object acts in the same direction as its acceleration. Therefore the resultant force on an object moving with uniform circular motion is inwards towards the centre of the circle. Don't be confused by the outward pull you feel when you whirl something around on a string. The force you feel is on your hand not the object. The force on the object is inwards.

The variables which affect the size of the force required to maintain a circular motion are the mass of the object, the radius of the circle and the frequency of rotation of the object. The aim of the experiment is to discover the relationship that exists between the force required to maintain uniform circular motion and each of these variables.

The uniform circular motion will be created by using a nylon line to attach a rubber ball to the shaft of an electric motor which will whirl the ball in a circle at constant speed. The Saunders Circular Motion Kit from IEC comes with a motor and mounting shaft, three different lengths of line and three balls of different mass.

1. Measure the mass of each ball. State your results in grams and kilograms.

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2. Calculate the magnitude of the weight of each ball.

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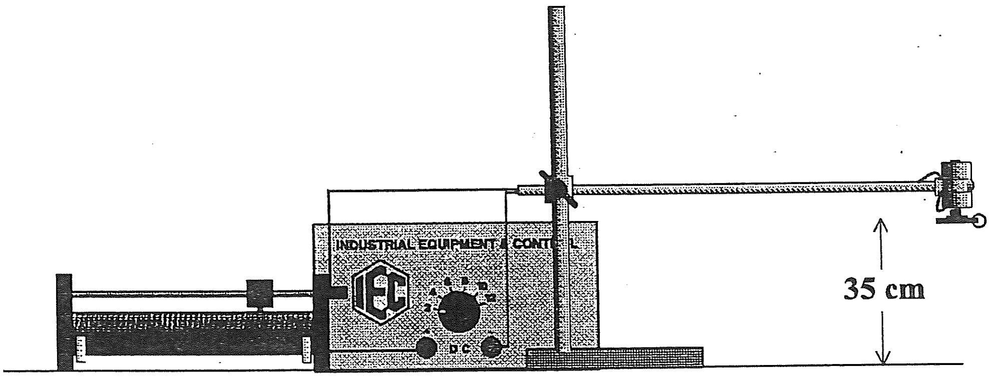
Arrange the apparatus as shown with the supply turned off and no line attached to the key ring in the plastic disc.



2 volt DC

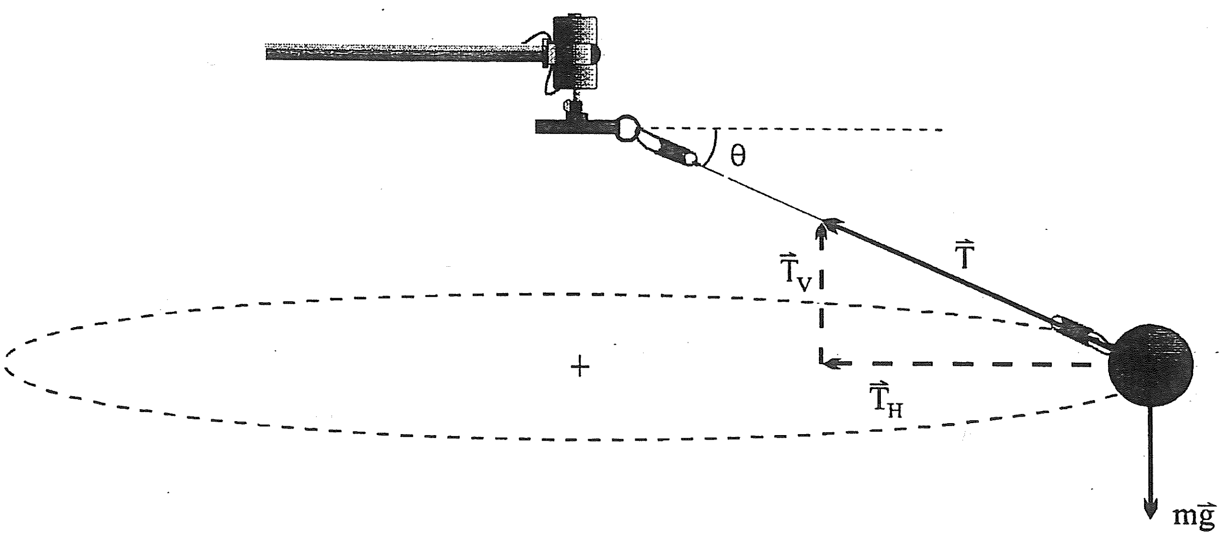
Set the rheostat so none of its resistance is included the circuit. Set the supply on 2 volt DC but **do not** turn it on. **Check that the plastic disc on the motor shaft is horizontal and not higher than 35 cm above the level of the desk.** This will ensure the ball will rotate below the eye level of a person seated.

Turn on the supply *very briefly* and determine in which direction the motor turns. Turn off the supply. Connect one end of the longest line to the medium sized ball and the other end to the motor shaft via the ring and the clips.

Hold the ball out from the motor so the line is at about 30° to the horizontal and launch it into a rotation in the direction that the motor turns. As soon as you release the ball, turn on the supply. Once a stable orbit is established, use a stop watch to check that the ball does not take less than 6 sec to complete 10 revs. If it does, increase the resistance of the rheostat. **Do not allow the ball to complete 10 revs in less than 6 sec at any stage of the experiment.** If it is not possible to get the ball to complete 10 revs in close to 6 sec, connect a voltmeter across the leads to the motor. Turn the supply to 4 V DC and increase the resistance of the rheostat so the potential difference across the motor is 2 V. **Do not allow the potential difference across the motor to exceed 2V DC at any stage of the experiment.** The motor may overheat. Now that you have observed the apparatus working, turn it off as the forces acting on the ball need to be analysed before data is collected.

PART A - FORCE AND FREQUENCY.

In the first part of the experiment, the relationship between the force required to maintain the motion F_{req} and the frequency of rotation of the ball will be investigated. The following diagram shows the forces acting on the ball during its motion (air resistance neglected).



The tension in the line has been resolved into its vertical $\vec{T}_V$ and horizontal $\vec{T}_H$ components.

3. In terms of $\vec{T}$ and θ, state the magnitudes of $\vec{T}_V$ and $\vec{T}_H$.

$\vec{T}_V$ = ________________ $\vec{T}_H$ = ________________

4. The ball moves in a horizontal circle. What is the resultant force on the ball in the vertical direction?

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5. What forces or components of forces act on the ball in the vertical direction?

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6. From your answers to Qs. 3, 4 and 5, state the magnitude of $\vec{T}$ in terms of m, g and θ .

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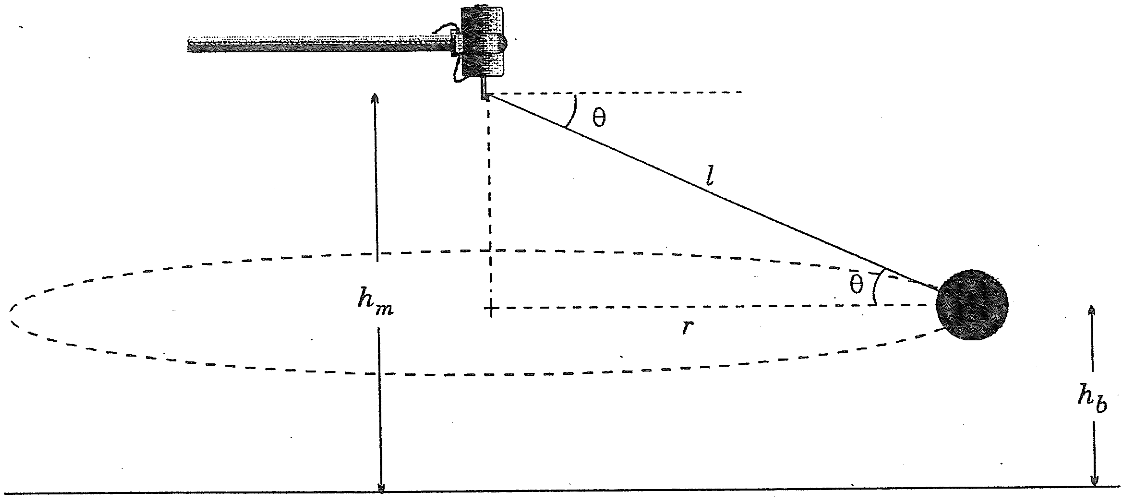
Since the vertical forces cancel out, the only force which is unbalanced is the horizontal component $\vec{T}_H$ of the Tension $\vec{T}$. Thus $\vec{T}_H$ must be the force required to maintain the motion.

7. State the magnitude of $\vec{T}_H$ in terms of $\vec{T}$ and θ.________________

If the proportion between the force required to maintain the motion and the frequency of the motion is to be determined, the radius of the motion and the mass of the ball should not change when the frequency is varied. If the line remained horizontal, the radius of the motion would remain the same when the ball was whirled around at different frequencies. However the angle of the line to the horizontal changes when the frequency is varied. This changes the radius.

The diagram shows the geometry of the length of the line l, the radius of the circle r, the angle of the line to the horizontal θ and the heights of the motor and ball above the desk h_m and h_b.



8. State the magnitude of r in terms of l and θ.________________________________

From Qs. 7 and 8, the same factor cos θ converts both the Tension into T_H and the length of line into the radius of the circle. Hence if the line stays the same length it does not matter that it dips below the horizontal. The proportion that exists between the force required to maintain the motion T_H and frequency at constant radius, is the same as the proportion between Tension and frequency at varying radius.

The Tension in the line can be calculated from the equation in Q.6, if the value of θ is known. The diagram above shows how θ can be calculated.

9. When the rotation is stable, the ball maintains a constant height above the desk h_b. Write an equation for sin θ using the variables h_b , h_m and l.

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10. From which property of the ball should measurements of its position be taken?

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11. Hold the ball so the line is taut and horizontal. Measure the distance from the shaft of the motor to the ball. What is the value of l ?

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12. What is the height h_m of the motor above the desk? Measure to the screw holding the plastic disc to the shaft as the line will be pointing in its general direction during the experiment.

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Set up the rotation as it was previously. With the aid of a stop watch, adjust the resistance of the rheostat so the ball completes **close to but not more than** 10 rotations in 6 sec. Stand a meter rule vertically on the desk and carefully move it as close to the ball as possible without touching it. When the rotation is stable, the ball will maintain the same height above the desk. As the ball flashes past, estimate the value of h_b. Record your result in the first column of the table below.

13. Without adjusting the rheostat, measure the time it takes for the ball to complete 10 revolutions. Repeat 2 or 3 times and complete the following.

Times for 10 revs ______________________________

Av. Time for 1 rev ____________ Av. Frequency of Motion ____________

Increase the resistance of the rheostat slightly so the rotating ball reduces its height above the desk by about 3 cm and allow the ball to stabilize its motion. Repeat the measurements of frequency and h_b. Record all results in the table. Continue reducing h_b in 3 cm steps until any further reduction in frequency will cause the value of h_b to become less than 5 cm. Stop making measurements and turn off the motor.

14.

h_b	Times for 10 revs.	Av. freq	sin θ	Tension	

15. Supply the correct unit for each of the columns of the table. The blank column will be used later in the experiment.

16. Use your answer to Q. 9 to calculate the value of sin θ for the first line of the table.

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17. Use your answer to Q. 6 to calculate the Tension in the line for the first line of the table.

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18. Calculate Tension and frequency for all of the rows in the previous table.

19. What additional value of the Tension and the frequency to which it corresponds, could be added to this table without any extra measurements being taken? ____________________

20. Draw a graph of Tension versus frequency.

21. If the relationship between T and f is $T \propto f^2$, what would be the shape of your graph?

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22. Could the relationship in Q. 21 satisfy your graph? ______________________________

23. To determine if $T \propto f^2$ is correct, against what quantity would you graph T? __________

24. If your supposition is correct, what do you expect will result from the graph of Q.23?

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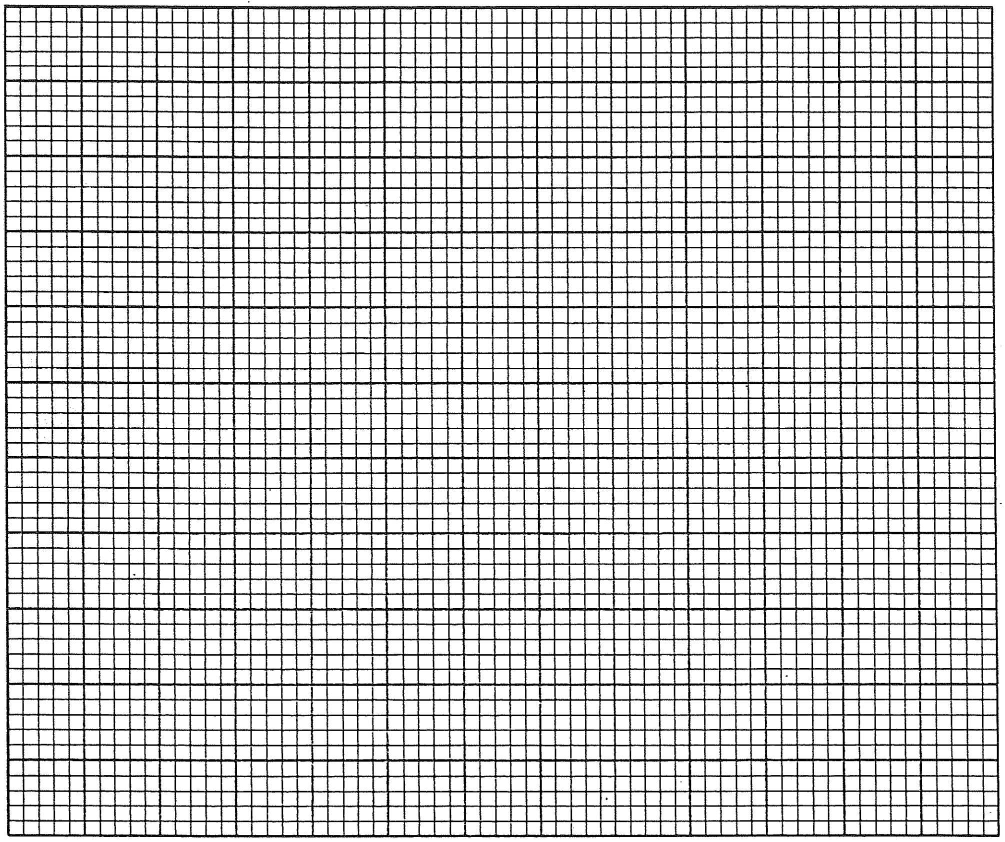
25. Head the blank column in the table of Q.14 with f^2 and enter the values of the squares of the frequencies.

26. Supply the correct unit for the f^2 column in the table.

27. Graph T against f^2. Use scales that will allow for Tensions of approx. 0.5 N and f^2 values of approx. 3 sec^{-2}. They will be plotted on this graph in later parts of the experiment.



28. What is the relationship between T and f^2 ?____________________________________

29. Hence what is the relationship between the force required to keep the ball moving in a circle at constant speed F_{req} and the frequency of the motion f when the radius remains constant?

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PART B - FORCE AND RADIUS.

To find the relationship between F_{req} and the radius of the circle, the mass of the ball and the frequency of the rotation must remain constant. The mass of the ball is easy to keep constant. However stopping the motion, changing the length of the line and re-creating the same frequency is not possible. Recall that in part A it was established that the same relationship exists between F_{req} and the radius of the circle as exists between Tension and the length of the line. Data of Tension and length of the line at constant frequency will need to be obtained graphically and in this section you will learn this method of analysis.

30. Connect the medium sized ball to the motor with the medium length line, measure the distance between the motor shaft and the ball with the line taut and state your result.

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31. Establish the ball in a stable orbit so it completes 10 revs in just over 6 sec. Make the measurements needed to determine the frequency of the motion and the Tension in the line as in part A, but for only one frequency of the ball. Record your results in the table. Repeat the procedure with the shortest line. Then turn the motor off.

wire len.	h_b	Times for 10 revs.	freq.	sin θ	T	$freq^2$

32. Plot the two values of (T, f^2) on the graph of T versus f^2 in part A.

33. If more values for T and f^2 were found for the medium and short lines and they were all plotted on the above graph, what would be the shapes of the two new graphs?

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34. Use the two points you have plotted to draw the two graphs more data would produce.

35. Next to each graph, write the value of l and the mass of the ball that was used to obtain the data.

36. The frequency of the ball must be kept constant if the relationship between F_{req} and radius is to be found. This can be achieved theoretically on the T versus f^2 graph by drawing a vertical line up from the $f^2 = 2\ sec^{-2}$ point on the horizontal axis. Do this on your graph.

37. Determine the values of T and l for the three points of intersection of the vertical line and the graphs. Tabulate your results and plot the appropriate graph.

38. What is the relationship between F_{req} and radius when the frequency of the motion remains constant?

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PART C

39. If the relationship between the force required to maintain motion in a circle and the mass of the object is to be investigated, which variables need to be kept constant?

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40. Describe the method you will follow to determine the relationship between F_{req} and m.

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Use the medium length line during this investigation.

41. Follow your procedure and tabulate measurements and calculations.

42. Tabulate values for Tension and mass and use them to plot the appropriate graph.

43. What relationship exists between F_{req} and m?

44. This relationship could have been predicted at the start of part C. Why?

45. Combine the relationships between F_{req} and frequency, radius and mass into one statement.

46. The force required to maintain motion in a circle was an often used phrase in the experiment. It would be advantageous to give it a name. Suggest one.

47. Check that you have included units in all tables, on axes of graphs and in recording of measurements. Check that you have not quoted too many significant figures in your calculations.

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