Ozobot Bit Classroom Application:

Linear and Angular Kinematics

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Topics

Science, Physics

Ages

Grades 10 – 12

Duration

30-45 minutes

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Introduction

The study of the motion of an object in physics, without regard to the object's mass and forces causing the motion, is known as ***kinematics***. In *another* Ozobot Bit classroom application, ***Velocity as Slope of Position vs. Time Graphs,*** the kinematics of motion on a straight line is investigated. In *this* classroom application, students will contrast linear and angular kinematics of Ozobot as he moves in circles. In the process of this investigation, students will learn about ***radians*** as a measure of angle and how to measure ***angular speed*** in radians per second. In addition, students will calculate Ozobot's ***radial acceleration***, also known as ***centripetal acceleration***.

Degrees versus Radians as a Measure of Angle

The measurement of angles commonly uses degrees through the study of geometry. However, in most studies of mathematics and physics beyond geometry, angular measurement is described in radians. Figure 1 can be used as an aid to understand the difference between degrees and radians.

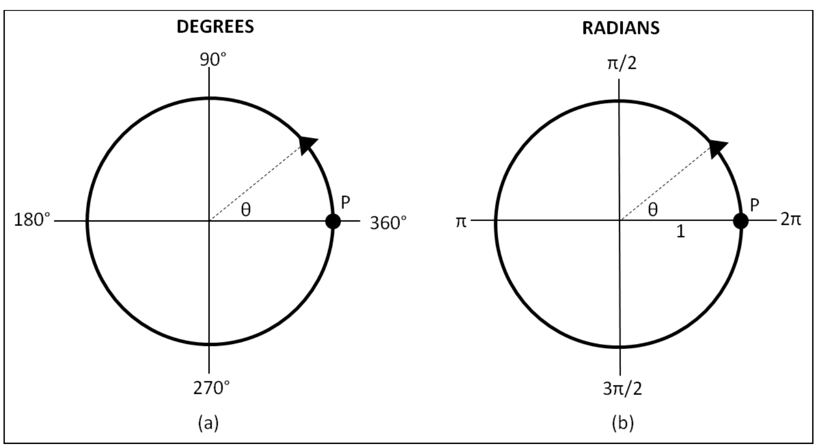

Figure 1

Consider degrees first by observing Figure 1(a). Starting at point P and moving counter-clockwise, an angle θ is created. As θ increases, an angle of 90°, a right-angle, is created. Continuing to a straight-angle, an angle of 180° is created. One complete circle results in θ = 360°. Once more around the circle would result in θ = 720°.

Now consider radians by observing Figure 1(b). Radians are defined on the basis of a unit circle, *i.e.*, a circle with a radius of 1. The length of the arc which θ subtends is the radian measure. A quarter of a circle is therefore π/2 radians, a half circle is π radians, three-quarters of a circle is 3π/2 radians, and a full circle is 2π radians. Two full circles would subtend an angle of 4π radians. For a *general circle of radius r*, the magnitude of the angle subtended by θ would the same as the ratio of the arc length, L, divided by the radius. Therefore,

$$\theta = L/r \quad \text{or} \quad L = r\theta. \qquad \textit{Equation 1}$$

It is seen that radians, θ, are pure numbers without dimensions since they are the ratio of two lengths, *L* and *r*.

Radians are commonly used in physics to describe angular measurements. For example, angular speed would be described in radians/second, or rad/s in short. Angular acceleration would be described in radians per second per second, or rad/s^2 in short. Since radians are pure numbers, when dealing with dimensional analysis, the units for angular velocity would be s^{-1} and the units for angular acceleration would be s^{-2}.

The OzoMap for this Classroom Application

As shown in Figure 2, the OzoMap for this classroom application has Ozobot starting in the lower left corner. He then follows six semicircles labeled 1 through 6, in that order. These six semicircles are laid out in such a way that Ozobot follows a spiral. There is ***no*** OzoBlockly program required for this classroom application. Ozobot is started at the location labeled "Start" by pressing the start button ***once***. Ozobot will then travel at a constant speed, i.e., his default speed, as he moves around the spiral. Either Ozobot 1.0 or Ozobot Bit can be used. By taking appropriate measurements described in the next section of this document, students will be able learn some concepts related to angular kinematics. Note that a larger copy of the OzoMap, suitable for copying and use by students with an Ozobot, can be found on the last page of this document.

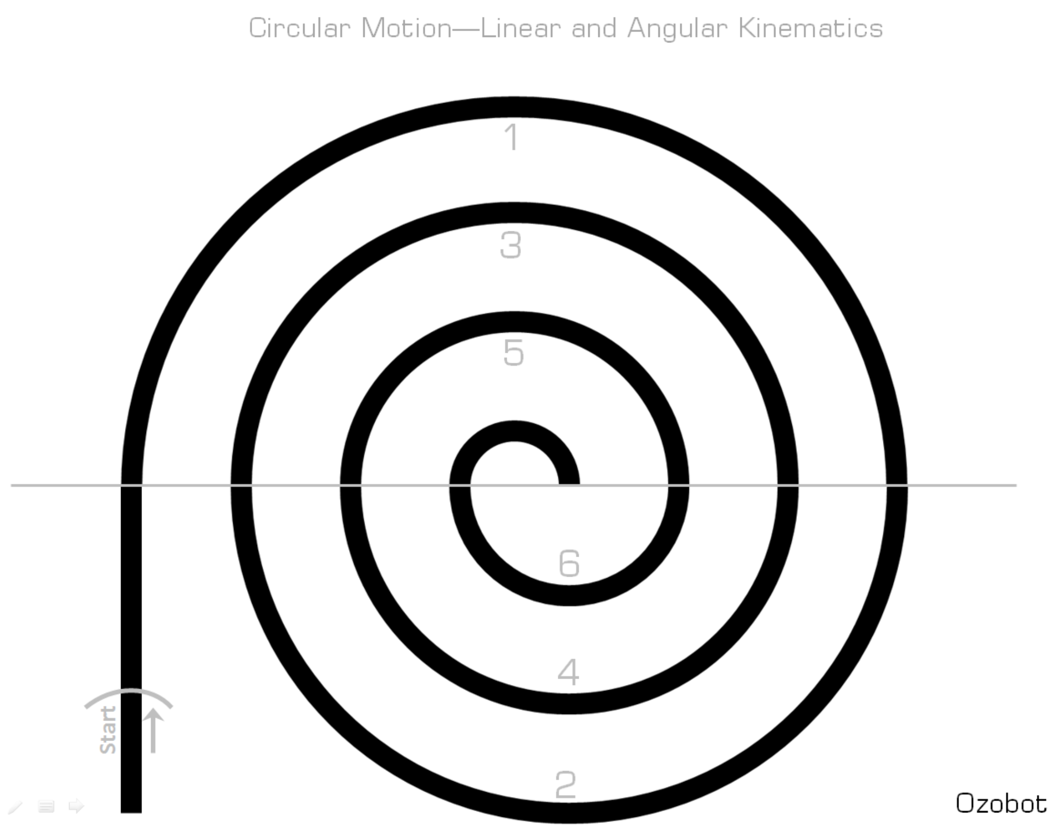

Figure 2

The Angular Kinematics Experiment

Each student lab group needs one Ozobot 1.0 or Ozobot Bit, which is placed at the location labeled "start" on the OzoMap, and facing the direction shown by the arrow. Ozobot is then started by clicking the start button ***once***. The horizontal gray line on the OzoMap is used to separate the semicircles 1 through 6 of decreasing radii. Before taking any quantitative measurements, have the students think about and discuss the following three questions by making some qualitative observations:

1. Does Ozobot appear to have a constant *linear* speed as he travels inward on the spiral? *[Yes, his linear speed is constant with a value equal to the default speed of Ozobot.]*
2. Does Ozobot appear to have a constant angular speed, say in degrees per second, as he traverses the spiral? *[No, his angular speed increases as he traverses the spiral. He revolves 180° on each of the semicircles, but it takes him less time to do it as he gets closer to the center of the spiral.]*
3. How many radians does Ozobot traverse for each of the six semicircles? *[Ozobot traverses π radians for each of the six semicircles. This is a good time to discuss radians if the students are not familiar with radians as a measure of angle.]*

Now that the student lab groups have completed some qualitative observations of Ozobot's motion on the spiral, they should be ready to collect some quantitative data. Each group will need a metric ruler to measure and record the diameter of the six semicircles. They should record the diameter to the nearest 0.1 cm in the provided data table on the next to the last page of this document. Using the horizontal gray line as a guide, diameters should be measured at the ***centers*** of the thick black lines that Ozobot traverses. Half the diameter will then give them the radius.

Stop watches should also be provided so that the lab groups can record the time required for Ozobot to travel each of the six semicircles. Alternatively, students can use a stopwatch app on their cell phones. In either case, it is suggested that times be recorded to the nearest 0.01 second. The horizontal gray line can be used as the starting and stopping location for each of the time measurements. It is helpful if the stop watch can provide "lap" times, where a lap is the time to traverse each of the semicircles. If clicking the stopwatch only displays *total* time since the start of semicircle 1, then lap times can be obtained by calculating *differences* in times. The table of Figure 3 is provided for the teacher as an example of typical data that lab groups may obtain.

Semicircle #	**Diameter (cm)**	**Radius (cm)**	**Semicircle Time (s)**	**Angular Speed (rad/s)**	**Linear Speed (cm/s)**	**Radial (Centripetal) Acceleration (cm/s^2)**
1	17.8	8.90	9.68	0.325	2.89	0.94
2	15.3	7.65	8.49	0.370	2.83	1.05
3	12.7	6.35	7.00	0.449	2.85	1.28
4	10.2	5.10	5.88	0.534	2.73	1.46
5	7.6	3.80	4.39	0.716	2.72	1.95
6	5.1	2.55	3.35	0.938	2.39	2.24

Figure 3

Here are sample calculations for the data shown in Figure 3 for semicircle #1:

- *Diameter:* 17.8 cm, obtained by measurements with a metric ruler.
- *Radius:* Half the diameter. 17.8 cm / 2 = 8.90 cm.
- *Semicircle Time:* 9.68 s, obtained by measurements with a stopwatch or stopwatch app.
- *Angular Speed:* In rad/s, since we have semicircles, the angular speed is π/semicircle time = π/9.68s = 0.325 rad/s.
- *Linear Speed:* Length of semicircle arc / semicircle time = π·Radius/time = π·8.90cm/9.68s = 2.89 cm/s.
- *Radial (Centripetal) Acceleration:* From physics $a_c = v^2/r = (2.89\ cm/s)^2 / 8.90cm = 0.94\ cm/s^2$.

Preparation for the Lesson

1. Make a copy of the last two pages (data table and OzoMap) of this document for each lab group.
2. Make sure that the Ozobots are fully charged, calibrated for paper, have clean wheels, and the motors are tuned.
3. Students should start their Ozobots by pressing the start button ***once***, with Ozobot at the start location on the OzoMap and facing the direction shown by the arrow.

Data Table for the Ozobot Angular Kinematics Experiment

Semicircle #	Diameter (cm)	Radius (cm)	Semicircle Time (s)	Angular Speed (rad/s)	Linear Speed (cm/s)	Radial (Centripetal) Acceleration (cm/s^2)
1						
2						
3						
4						
5						
6						

Questions:

1. Do the data in the *Linear Speed* column of your data table agree reasonably well with your earlier qualitative observations regarding linear speed? Explain.

2. Do the data in the *Angular Speed* column of your data table agree reasonably well with your earlier qualitative observations regarding angular speed? Explain.

3. Does Ozobot appear to be experiencing an *angular acceleration* as it traverses the spiral? Explain.

Circular Motion—Linear and Angular Kinematics