Spirotating Cylinder
(**Spi**nning & **rotating)**

The spirotating cylinder is documented here:
http://www.exploratorium.edu/snacks/spinning-cylinder and in the **Square Wheels** book. We also explored the motion of cylinders and that is included here.

Materials: PVC Pipe & permanent Markers

A focused version of this activity uses pipes whose length is a multiple of the diameter (3 times the length, 4 times the length, 5 times the length). Multiple diameters of pipe (1/2", ¾", 1 ")

An open-ended version of this activity allows students to cut their own pipes to investigate these phenomena.

FOCUS QUESTION for students: How can we make this cylinder move (without throwing it)? List as many types/ways of making it move as possible. Describe these possible motions.
Next: You've generated a lot of motions. **How can we group these motions?** Instead of having all of the types of motion suggested, can we instead list some basic motions that ALL other motions listed can be made up of?

Focus Question 2: For a Spirotating (spinning and rotating) tube: Does the length of the tube change the number of marks you see? If so how? What's the relationship. You might use string (or a tape measure) to measure the different dimensions.

Focus Question 3: For a Spirotating tube: Does the width of the tube change the number of marks you see? If so how? What's the relationship. You might use string (or a tape measure) to measure the different dimensions.

Focus Question 4: What would we see if we spun this tube on the inside of a bottle? How does the bottle's size affect the number of marks you saw? Does where you are affect the X's you see? How many x's appear on the bottle if you look from all angles? Why?

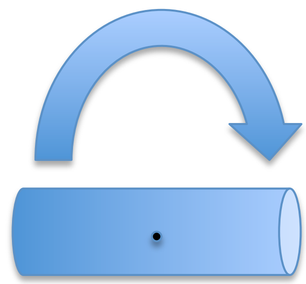
Focus Question 5: When I press on the side with the X, just the X appears. What's going on? Do you think it's the same sight on the bottom of the tube (if you could see the bottom of the pipe, would the X's still appear?) Try It. What other things might allow you to see what's going on?

Focus Question 6: For a Spirotating (spinning and rotating) tube: What would happen as X's get farther away from the ends of the pipe, and move towards the center? Are X's in the center more clearly seen, or less clearly seen? Do you see a different number of X's?

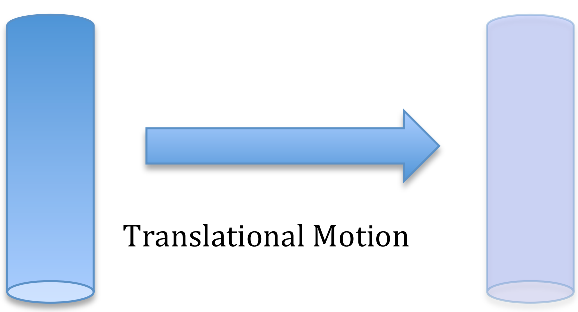
Q1: How can we make this cylinder move & how can we group these motions?

For the Teacher: This is what science often consists of – breaking apart complex pieces to see the simpler elements it can be thought to consist of. In this example, it's worthwhile to decide in groups or as a class what a good way of breaking apart the motion might be. Students can come up with many viable options. A scientist might say that there is forward or better yet, translational motion (overall motion in the x, y or z direction relative to the lab/observer), then there is motion around certain axes going through the PVC. One we will arbitrarily call 'spinning' – which will be the motion of the cylinder around the long axis as if it was on a spit like a hot dog (or if you put the pvc on a pencil and spun it while holding the pencil). The other we will call 'rotating' which occurs around an axis perpendicular to the table so that the cylinder's ends move while it's center doesn't.

Axis of spinning



Axis of rotation (in line with diameter of cylinder)



Original Location

Final Location

Focus Question 2: For a Spirotating (spinning and rotating) tube: Does the length of the tube change the number of marks you see? If so how? What's the relationship. You might use string (or a tape measure) to measure the different dimensions.

Teacher: A pattern does start to emerge. Simple patterns: the longer it is the more items you see (on the side you start at) More complex pattern: Take a look to see how the length compares with the diameter. Relate that to the number of Xs you see.

Focus Question 3: For a Spirotating tube: Does the width of the tube change the number of marks you see? If so how? What's the relationship. You might use string (or a tape measure) to measure the different dimensions.

Teacher: A pattern does start to emerge. Simple patterns: the wider it is the fewer items you see (on the side you start at). More complex pattern: Take a look to see how the width compares with the diameter. Relate that to the number of Xs you see.

Focus Question 4: What would we see if we spun this tube on the inside of a bottle? How does the bottle's size affect the number of marks you saw? Why?

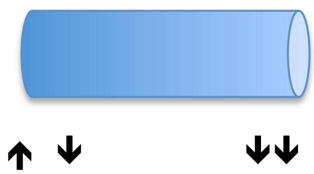
Teacher: A pattern does start to emerge. However one aspect is actually seeing the sides of the tube when it's spinning. If you can see all around the tube, then a pattern should emerge. More complex pattern take a look to see how the circumference of the pipe relates to the circumference of the tube it spins inside.

Focus Question 5: For a Spirotating (spinning and rotating) tube: When I press on the side with the X, just the X appears. What's going on? Do you think it's the same sight on the bottom of the tube (if you could see the bottom of the pipe, would the X's still appear?) Try It. Can you take a look at the spinning tube from the side to see what area(s) are touching the ground surface? What other things might allow you to see what's going on?

Teacher: This is a pretty difficult thing to see on your won, but if we go back to question 1, the spirotating pipe uses 2 motions – spinning and rotating. The mirror shows you something different than just looking at it. Try looking at the piep from the side as well. It turns out that motions add & subtract and this is called Galilean Relativity. Essentially if a ball is stationary on the bus and the bus goes 60 mph east, then the ball goes 60 mph East. If the ball was in the bus and rolling forward in the bus at 5 mph, while the bus was going 60 mph then the ball would really be going 60 + 5 = 65 Mph. Meanwhile if it was rolling backwards on a bus moving forwards the ball would really be going 60 – 5 mph = 55 mph.

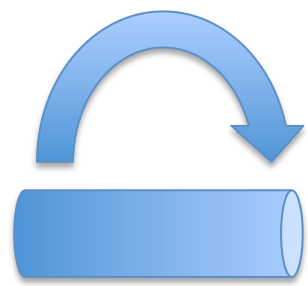
For our pipe it is spinning and rotating and those speeds add:

Due to the spinning both sides of the pipe move toward the bottom of this page. However due to the rotating, the right side moves toward the bottom of the page, while the left side moves towards the top of the page. So the right side has two speeds: spinning and rotating towards the bottom of the page on the right, and the left side goes up towards the top of the page due to rotation, but down towards the bottom of the page due to spinning. This means that the left side should go faster (bottom + bottom) while the right side should go slower (top – bottom) (actually it doesn't mover horizontally).



Resulting speeds

Axis of spinning



Axis of rotation (in line with diameter of cylinder)

This relates to what happens when a tire rolls along the ground. If you put your hand on my hand and it slips then it moves relative to my hand, but if it stays right no top of my hand – not slipping then it has no motion relative to my hand. This means that slippage indicates a relative motion, while no slippage means no motion. If a tire slips against the ground then it is moving relative to the ground, but if not, then the very bottom of the tire (since it's not slipping) must be motionless relative to the ground!!! The bottom of the tire on a car that is moving forwards spins backwards while it rolls forward, meaning no net motion relative to the ground! The middle (axis) of the tire doesn't have any spinning speed, but it moves forward with the car. The top of the tire spins forward and rolls forward – giving it double the speed relative to the ground!

NEXT: Why the number of images? In actuality the cylinder is riding along one edge of the PVC, meaning that the right side actually spins and rolls along the ground, while the left side lifts upwards. This means that one side is actually rolling along the ground. Since each roll of the pipe is circumference of the pipe (**π** x the diameter) we know how much ground it covers, but it also rolls around a circle with a circumference the length of the cylinder (**π** x the length of the cylinder). Let's take

a pipe whose length is 3 x the diameter (l = 3d) Then the large circle it rolls around is:
Large Circle = **π** x length of cylinder *(substitute length of cylinder = 3 x diam. of cylinder (3d))*
Large Circle = **π** x 3 x d *(rearrange this…commutative property)*
Large Circle = 3 x **π** x d *(wait: Pi x d = the circumference of the small pipe)*
Large Circle = 3 x small pipe

So since the small pipe rolls three times to complete the large circle we see 3 Xs because the reach the top of the pipe 3 times!
If you want to see the X four times you can make the pipe 4 x as long as the diameter!

Focus Question 6: For a Spirotating (spinning and rotating) tube: What would happen as X's get farther away from the ends of the pipe, and move towards the center? Are X's in the center more clearly seen, or less clearly seen? Do you see a different number of X's?

Teacher: As the X's go in towards the center away from the one end where you see the X clearly, we find that the X starts to blur, then disappear because it is spinning and it doesn't have as much counter-motion from the rotation. In the dead center of the pipe the center of the X is just spinning around rapidly, and the X is rotating around its center! While one part of the X goes up, the other part goes down! Essentially at one end of the pipe, the X is temporarily stationary, while at the other end of the pipe the X is going super-fast (per **Q5**). In between the two ends there are a range of motions from slow to fast.

GOING FURTHER: We suggest making an engineering challenge. Ask the students to create a pipe that shows 6 Xs. The students could make the pipe 6 x as long as the diameter, or they could put 2 Xs on the side you spin and only make the pipe 3 x as long as the diameter, or they could possibly do other things to get you 6 Xs – you just don't know!

This has been a LIGO Science Education Center interpretation of the Spirotating activity. It is worthwhile to note that Galilean Relativity and the constancy of the speed of light posed vexing problems for physicists – problems solved by Einstein's Special Theory of Relativity. Einstein's General Theory of Relativity expanded upon this, and lead to predictions of Gravitational Waves that LIGO is currently looking for! Questions and thoughts can be sent to wkatzman@ligo-la.caltech.edu