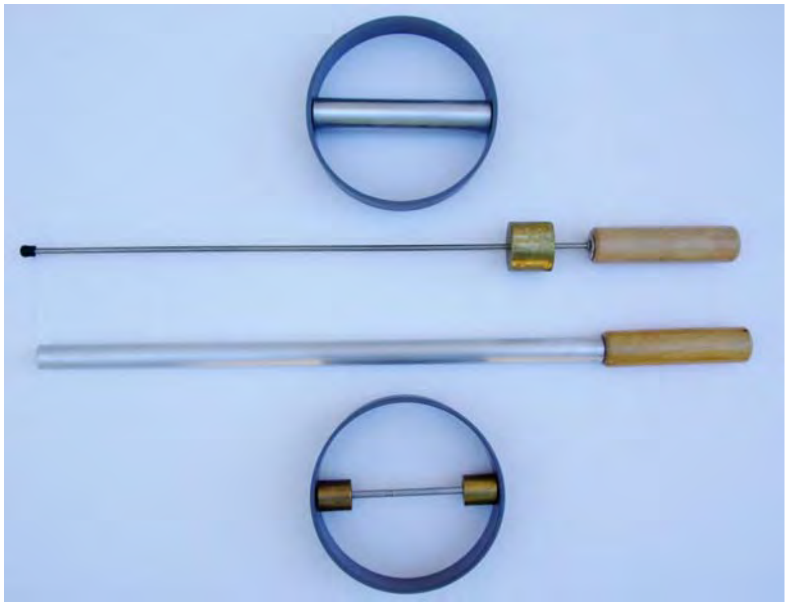
611-0405 (40-310) Moment of Inertia Set



Introduction: Inertia is all around us, although most of us pay little heed to it. It is the reason why cars need brakes, why a large man is harder to shove than a small man, and why it is so difficult to get a bicycle moving.

The concept of inertia, in one form or another, has existed for millennia. Aristotle did not believe in inertia, and instead believed that it was the natural tendency of all objects to be at rest. Some of his contemporaries challenged this notion, stating that an object would keep moving unless some force opposed it. This concept is the beginnings of inertia.

There is evidence that some Chinese and Islamic philosophers developed similar views. However, as far as science is concerned the first true definition of inertia was set forth in *Principia Mathematica*, the famous work by Isaac Newton. In Newton's words, the idea went thusly:

"The vis insita, or innate force of matter is a power of resisting, by which every body, as much as in it lies, endeavors to preserve in its present state, whether it be of rest, or of moving uniformly forward in a straight line."

In simpler language, this means that a moving object will continue to move in the same direction and at the same velocity, unless acted upon by a force. By the same token, an object at rest will stay at rest unless a force sets it into motion. This is the concept of inertia, and in fact forms the basis for Newton's First Law of Motion.

Inertia can sometimes be difficult for students to understand, because it deals with both moving and stationary objects. For example, a racecar at the starting line has a certain inertia. Its mass requires a certain amount of energy to get into motion and to accelerate. However, once the car has reached its top speed, the energy required to keep it moving is far less than the energy used to accelerate. After the car crosses the finish line, it will coast to a stop. While coasting, it slowly loses its velocity to friction. The greater its velocity, the more time it will take to stop. This is because a heavy object like a car, if in motion, has built up energy that must be eliminated before the car can stop. Thus, the car has inertia. This is why the term *inertia* can describe the energy of an object whether it is moving or at rest.

There is a second kind of inertia: *moment of inertia*. This applies to rotating bodies. It is sometimes referred to as *rotational inertia* or *angular mass.* In short, it describes the resistance a body has toward changing its rotation. For example, consider the Earth. Earth rotates at more than 1,000 miles per hour, and has a mass in excess of 6.5 *sextillion* tons! (Sextillion is a 1 followed by 21 zeroes). That much mass moving that fast has an awful lot of momentum, or inertia. Imagine how difficult it would be to stop Earth's rotation! You would need vast amounts of energy, an unimaginably long time, or both to complete the task. Computing the energy required might make a good **extra credit** assignment for your students.

On a smaller scale, rotational inertia also applies. Motorcycle tires spinning at high speeds develop quite a bit of inertia. This is why racing motorcycles never seem to tip over; the force required to change the direction of the rotating tires is so high it is almost impossible to turn them 90 degrees.

Moment of inertia also plays an important role in gyroscopes, for the same reason.

In this kit, we have included examples of both kinds of inertia.

Description: In this kit, you will find two rings, and two wands. The wands are of approximately equal mass to each other, as are the rings.

1. For the first experiment, use the wands. You will notice that one is a thick shaft of aluminum, while the other is much thinner but has a moveable brass weight. To begin, slide the brass weight all the way to the handle of the wand. Ask your students to pick up the wands and tell you which is heavier.

2. Most of the students will tell you the aluminum wand in heavier. It is very important not to tell your students that the wands are actually the same mass.

3. Next, slide the brass weight to the opposite end of the wand. Lay the two wands next to each other, and have your students pick them up. Ask which one feels heavier.

4. Most of the students will say that the brass wand feels heavier. This will confuse them, as just a minute ago they clearly felt that it was the lighter of the two!

5. Why do the wands behave like this? It is a matter of balance. When the brass weight is pushed all the way against the handle, most of the wand's weight is close to the student's hand. This means that the tip of the wand is very light. If you think of the wand as a lever, the fulcrum would be next to your hand, with almost no mass pushing on the opposite end. This in turn makes the brass wand feel lighter than the aluminum one, which has is more evenly weighted.

    a. By the same token, when the brass weight is at the extreme end of the wand, it will feel heavier. Again, thinking of the wand as a lever, the fulcrum will still be near the user's hand. However, this time most of the mass is pushing down on the opposite end, creating a powerful torque. This in turn makes the wand feel heavier.

For the next experiment, we will use the rings. You will also need an inclined plane and a stopwatch.

1. Everyone has heard of the famous 'ring and disc' demonstration. This next experiment is similar, but with a few key differences. We still use the ring, but instead of a disc we are going to use a ring with brass weights inside. These weights are fully adjustable, from the center of the ring to the rim. Both rings have nearly equivalent mass; again, it is important not to tell your students this.

2. To begin the experiment, you will need to set up an inclined plane. This can be as simple as a board propped up against a few textbooks stacked on top of each other. Hint: if you use a board 1m long, velocity calculations will be greatly simplified. An angle of about 30° works best: it produces a dramatic demonstration, but happens slowly enough for careful demonstration. A stopwatch will help improve precision.

3. To establish a baseline for the experiment, place the ring at the top of the inclined plane and allow it to roll freely down. Using your stopwatch, measure how long this takes. It is best to get several runs and average the times.

4. After you have gotten an average time for the plain ring, you will need to compute the velocity. This is done by dividing the distance traveled by the time. For example, if it took the ring 2 seconds to roll down a 1m long ramp, its velocity is 0.5 m/s. You will compare the velocity of the second ring against this baseline.

5. Taking the second ring, push the brass weights into the center. Roll it down the ramp. When you compute the velocity, you should find that it is slower than the baseline.

6. Next, push the brass weights to the outer rim of the ring. Tell your students that you are going to make the ring travel much faster than before. Since your students saw the second ring move slower than the baseline a minute ago, most of them will not believe you.

7. Roll the ring down the ramp. It should be measurably faster than the baseline.

8. How can this be? Recall when we talked earlier of angular momentum. The force accelerating the ring is gravity. If we think of the ring as a lever, with invisible 'spokes' connecting the rim and center, the force on the rim will be amplified versus the force on the center. If more mass is located in the center than on the rim, it will be that much harder to accelerate the ring.

9. Conversely, when nearly all the mass is concentrated on the rim, the ring will speed up. This is because of the multiplier effect of the lever; more mass means more force on the rim, which is amplified by virtue of being farther from the center. In the case of our ring, nearly all the mass is located on the rim, with almost none in the center. This means that nearly all of the force applied to the rim via gravity is used to accelerate the ring, with very little wasted in overcoming the mass in the center.

10. By adjusting the masses, it is possible to create some interesting effects.

    - It is possible to move the masses until the second ring has the same weight distribution as the first. They should now move at the same velocity.
    - By placing all the mass on just *one side* of the ring, it will have a very hard time rolling down the ramp. It may roll a little way and then stop. Under some circumstances, it may even roll uphill a little!

Warranty and Parts:
We replace all defective or missing parts free of charge. Additional replacement parts may be ordered toll-free. We accept MasterCard, Visa, checks and School P.O.s. All products warranted to be free from defect for 90 days. Does not apply to accident, misuse or normal wear and tear. Intended for children 13 years of age and up. This item is not a toy. It may contain small parts that can be choking hazards. Adult supervision is required.

May we suggest:

611-1215 Ring and disc: Simple materials of the same mass and diameter - a Steel Ring and Wood Disc, each 3" across - demonstrate mass distribution in rolling bodies. Roll them together down an incline and time which is faster. Instructions included. Weight: 1 kg.

611-1135 Acceleration paradox: Here's an exciting way to show acceleration. When a ball and board are released together, the end of the board outstrips its center of mass, leaving the ball behind. The ball then drops straight into the cup. Includes: two 1 meter boards, hinged together but separated by a dowel, a cup for the included ball, and instructions.