Forecast:
Balancing Acts
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The Relaxation Times

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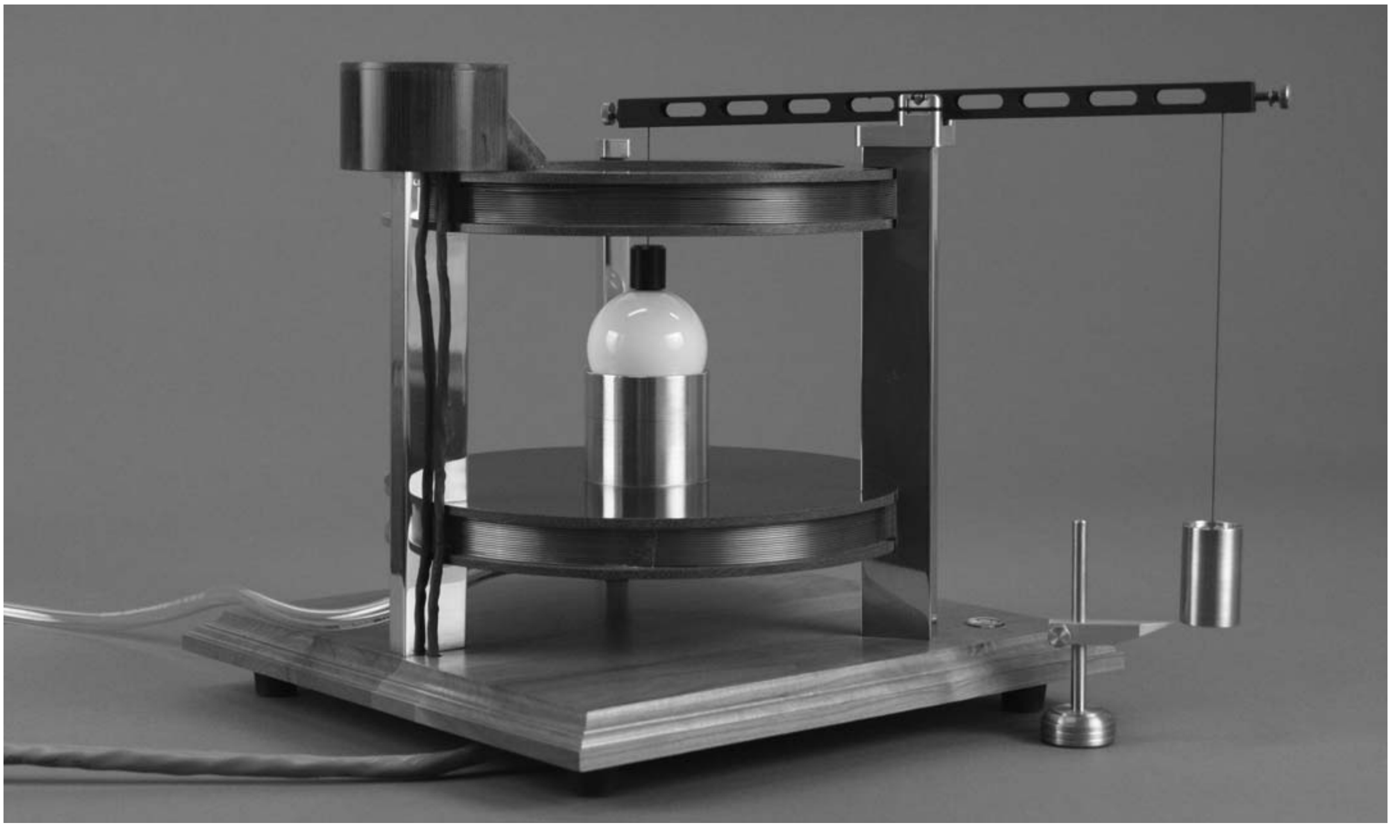
Magnetic Force Balance

(A New Addition to Magnetic Torque)

The "Teeter - Totter"



It's funny how some names stick, even when you wish they wouldn't. That's particularly true for personal nicknames which often become embarrassments when they hang around after childhood. That seems to be the situation here at TeachSpin for our newest addition, the Magnetic Force Balance addition to our "New Classic", Magnetic Torque. I have wanted to add this balance to Magnetic Torque for many years, but the other projects always seemed to have a higher priority. So please accept my apologies for the delay. Now, the Magnetic Torque unit MT1-B comes complete with a Magnetic Force Balance Kit as a standard part. Say hello to our "Teeter-Totter".

I very much wanted this simple balance to be part of the Magnetic Torque unit because, with it, a student can measure the magnetic moment of the small NdFeB disk, imbedded inside the snooker ball sphere, **FIVE** independent ways. That's right **FIVE**! And, since the NdFeB disk is small compared to the plastic sphere in which it is imbedded, it is reasonable to think of the disk as a point magnetic dipole whose properties are analogous to the fundamental unit of magnetism, the intrinsic magnetic moment of the electron or proton. We like to think of our snooker ball with a NdFeB disk, as the world's fattest proton (missing only the electrical charge).

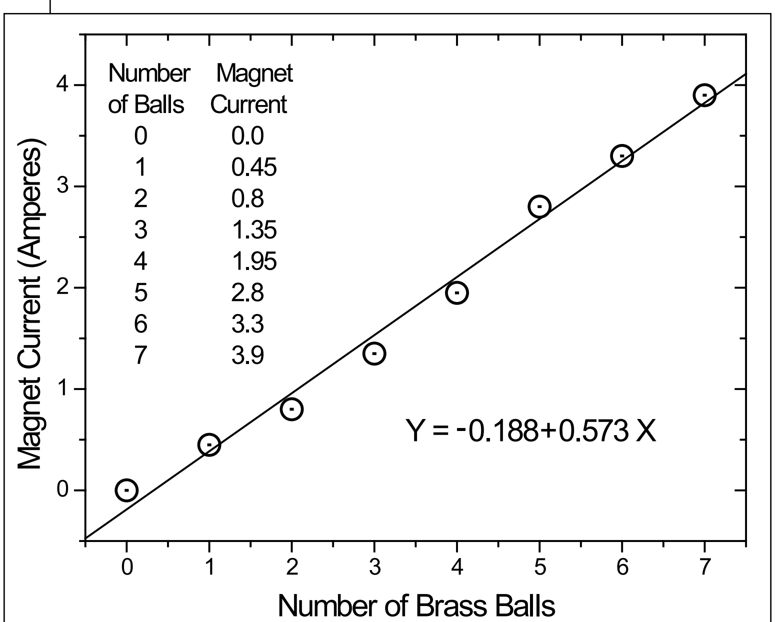
To measure the magnetic moment using the balance, students need to understand that translational magnetic forces on a magnetic dipole are caused by a magnetic field *gradient* not by a magnetic field. The mathematics is:

$$F_z = \mu_z \frac{\partial B_z}{\partial z}$$

The current in the Magnetic Torque coils can be directed so that it creates a uniform magnetic field gradient at the geometric center of the unit. Students can calculate the expression for the gradient as a function of the coil current I from the given geometry and number of turns in the coil. The answer they should obtain is:

$$\frac{\partial B_z}{\partial z} = 1.69 \text{ x } 10^{-2}\, I \quad \text{T/m } (I \text{ in amperes})$$

As you can see from the photo on the front cover, the sphere is balanced by a counter-weight such that when the magnetic field gradient is zero, the beam is horizontal. The level is marked at the end of the counter weight. Now a single brass ball is added to the counter weight, tipping the balance beam and raising the ball above the air bearing (which is not operating). The magnetic field gradient current is then turned on and adjusted to return the beam to the original equilibrium position. The value of the current is recorded. This procedure is repeated several times until the unbalanced weight is too large for the gradient current to return the beam to equilibrium. A graph of my data is shown below.



The analysis of the data is straightforward, but I will bet that the students will make mistakes with the units.

Note: 7 brass balls have a mass of 3.4 g
<mass of one ball> = 0.49 g

The balance condition is represented by:

$$mg = \mu_z \frac{\partial B_z}{\partial z} = \mu_z (1.69 \text{ x } 10^{-2})\, I$$

From the slope of the graph, with the appropriate unit conversion factors, my measurement yields a magnitude of the magnetic moment to be:

$$\mu_z = 0.50 \text{ amp}\cdot\text{m}^2$$

This value is in reasonable agreement (within 15%) with the other four independent measurements of the same quantity. (See if you can get the units right!)

In case you may not recall all the ways your students can use Magnetic Torque to measure μ, let me refresh your memory.

1. Static Force Balance
2. Static Torque Balance
3. Physical Pendulum Period
4. Precession Frequency
5. Magnetic Field Measurements

There are two static mechanics, two dynamic mechanics, and one E&M field measurement. The static torque measurement balances a gravitational torque created by an additional weight on a lever arm with the magnetic torque created by the uniform magnetic field on the NdFeB dipole. The physical pendulum is created by displacing the axis of μ from the direction of the uniform magnetic field, thus creating a restoring torque on the ball. The period of the harmonic oscillation is measured for small amplitude motion. If the ball is spun about the symmetry axis of μ, then it has both a magnetic moment and a collinear angular momentum. The ball now serves as a classical model of the proton, which will undergo precessional motion in the presence of a uniform magnetic field. And finally, using our Hall Effect Probe to make a careful measurement of the magnetic field of the ball along the symmetry axis of μ, will both demonstrate the $1/z^3$ dependence and give another measurement of the magnitude of μ.

Each of these measurements has its own systematic errors and each will yield somewhat different values of μ. The detailed analysis of these data can be as sophisticated as the instructor deems appropriate. However, carrying out all these measurements on a single ball gives the student a truly unique experimental, as well as theoretical, opportunity. Each measurement requires a different experimental skill. These are not particularly demanding skills, but they are important for the freshman/sophomore student to master. Even more important is the theoretical review of *both* classical mechanics and electricity and magnetism that is required. Just getting all the units correct for all five measurements will challenge most, if not all, students.

But let's not forget the "fun factor." You can mark these balls so that you have a "good" value for its magnetic moment and challenge the students to make careful and accurate measurements. These can be compared with your measurements. In my judgment, these experiments offer the physics students a chance to master fundamental ideas of Mechanics and E&M with an instrument that gives them an enormous "intellectual and experimental phase space". I believe every physics students should have this opportunity.

Jonathan

Magnetic Force "Recall"

Thank you Joe Raush of the University of San Diego for spotting a problem with our Magnetic Force Apparatus. We certainly missed it! The transparent millimeter/centimeter scale attached to the side of the Plexiglas tower is significantly out of calibration. For example, it measures a 15 centimeter length as 15.3 centimeters. The problem was caused by a shrinking of the transparent plastic tape on which the scales were printed five years ago. This will introduce a small error into the measurement of the magnetic moment of the NdFeB dipole.

We have had new scales made using a material our supplier assures us will not shrink over time. In any case, the new scales are accurate to ± 0.5 mm over the entire range and we will check them periodically to assure their continued accuracy.

If your Magnetic Force or Magnetic Torque apparatus has one of these inaccurate scales, we will send you a replacement kit which includes a new scale, some adhesive remover, and instructions for attaching the new scale. Call, write, or email us and we will mail you the kit at our expense.

Of course, you might choose to make "lemonade out of lemons." By that I mean, you could tell students that there is an error, give them an accurate scale, and ask them to determine the magnitude of the error and to adjust their data to compensate. Or, you could ask them to estimate the induced systematic error. It might be a good opportunity to show an example of systematic versus stochastic errors. The choice is yours.

We apologize for the inaccurate scales and we thank Joe Rauch again for discovering and alerting us to our mistake.

LISTSERV

For years, we have been putting people who own TeachSpin apparatus in touch with each other one by one. Now, we have a way of putting you in touch not only with other people using TeachSpin apparatus, but with a larger community of faculty and staff committed to advanced laboratory instruction. On November 27, the American Association of Physics Teachers (AAPT), launched a listserv focused on the Advanced Lab. You can just browse the site or join by going to the "address" below. The last letter is a lower case L for listserv

http://lists.aapt.org/cgi-bin/lyris.pl?enter=advlabs-l

Put together by AAPT President, Harvey Leff, the site offers lots of options. You can join or just browse. If you decide to join, you can choose to receive individual messages or get a once-a-day delivery in digest form. You can remain read-only or subscribe with a right to post messages yourself. You can even be a browser with the right to post messages.

AAPT is also working on an Advanced Lab website that will have lists of labs by topic, caches of how-to-build, where to buy and sample student labs. We'll keep you posted.

TEACH SPIN

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See You at The RALI

Reception for Advanced Laboratory Instructors

(Satellite Session)

APS March Meeting – Denver, CO

Adam's Mark Hotel – Governor's Square 14

Wednesday, March 7, 2007

6:00 pm to 8:00 pm

Sponsors: The APS Forum on Education and TeachSpin Inc.

The Event: To share ideas and plans for shining a spotlight on Advanced Laboratory Development and Instruction – while consuming some good wine and delicacies

Your Hosts: Barbara and Jonathan Reichert, TeachSpin Inc.
Peggy McMahan and Ernie Malamud, Forum on Education
Krishna Chowdary, Bucknell University
David Van Baak, AAPT Advanced Lab Task Force