The Milli-Can Experiment

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Background

Robert Millikan experimentally determined that electrical charge came in "lumps" (*Quanta* is the preferred term) of a certain minimum size. This minimum size is the charge on a single electron.

Millikan did this by finding the electric field required to levitate tiny oil droplets.[2, 3] From this field, and the mass of the droplets, he found the total charge on the droplets. After measuring many droplets, he determined that the total charge on any droplet was always some multiple of 1.6×10^{-19} C. This is the charge on a single electron, and (as far as we know) it is the smallest unit of charge available under normal circumstances.

Experiment

Experimentally, Millikan's work is beyond what we really want to do in a short lab period. Instead of measuring the charge of an electron, we will be using a conceptually similar procedure to find the mass of some Unknown Small Objects (USOs). The USOs will be inside sealed containers. Just as Millikan had no way of knowing ahead of time the number of electrons on an oil droplet, so you will not know the number of USO's in a given container. By measuring the mass of enough containers, you can determine the most likely mass of a single USO. The exact method you use for this determination is up to you. (But no, you may not open a container!) One good way of analyzing the data involves a linear fit on a graph of mass *vs* USO count, but there are many options.

Turn in a short ($\approx$ 1 page) summary writeup showing how you determined the mass. Your writeup *must* include an analysis of the uncertainty of your results. Be sure to consult a good reference on error analysis for assistance on this uncertainty.

Historical note

There is some fascinating history behind the measurement of the charge of an electron. As late as 1936, there were two different values for e, depending on which method was used to measure the charge. This uncertainty also affected the measurement of the wavelength of X-rays, which in turn affected the determination of Avogadro's constant. For a detailed discussion of this history, see Franklin Miller's 2007 article in The Physics Teacher, *Two Kinds of Electron?*[1]

Equipment

First off, you need 20–50 opaque canisters of approximately the same mass. Kodak 35mm film canisters are ideal for this. Film canisters can still be had for the asking at large film developers, although they're getting harder to find with the increasing popularity of digital cameras.

Next, you need USOs. These can be some set of identical objects with mass on the order of 3–10 grams: some ideas include:

- ball bearings
- machine screws
- pennies
- marbles

and so on. The variation in film-canister mass is roughly 0.2 grams, so make sure that your USO's have a mass significantly greater than this value, and a variation in mass significantly smaller. For the USO's in the workshop, I used 10-32×3/4 machine screws. Pennies are the most obvious choice, but I've found that the variation in penny mass is a large enough fraction of the average penny mass that it's difficult to see the steps corresponding to individual pennies.

Distribute the USOs randomly into the film canisters. It's overkill, but what I did was fill canisters so that the number of canisters with n USOs roughly matched a Poisson distribution. Having multiple canisters with the same number of USOs is an advantage in that it gives the students the opportunity to see the variation in canister mass. Occasionally this will result in students determining that the mass of a single USO is equal to the resolution of the digital scale, which can be educational. I would not recommend having a canister with zero or one USO, since the students seem to think that it's important to find such a canister and it really is not. I also put two cottonballs in each canister to make it more difficult to determine anything about the USOs by shaking canisters.

Finally, I labeled each canister so that one student does't inadvertently spend the lab period measuring the same canister 40 times. (Don't laugh. I'm sure you've had this student in your class also!)

Instructor's notes

This experiment is a very close analog to Millikan's work: but instead of using electrostatic force to measure electrostatic charge, we're using gravitational force to measure gravitational "charge" (mass). Just as Millikan had no way of knowing the number of electrons on an oil drop, we have no way of knowing the number of USOs in a canister.

The first step students should take to measure the mass of the USOs is to weigh each container. The best way I've found to analyze the weights is to sort the list of masses by mass, and note the rough stepsize m_o in masses. Assume that there are N USOs in the lightest canister, which has mass M_o, and $N + n$ in the rest, where n is some integer such that the total mass of each canister is roughly $M = M_o + nm_o$. A plot of M versus n will be linear, with a slope equal to the USO mass m. If the plot is *not* linear, there is probably an issue with the initial estimate m_o or with the assignment of n to the canisters.

Note that the intercept of the above plot will be the mass M_o. If N is chosen accurately, this gives the mass of an empty canister.

Sample Data

The masses of one set of canisters is shown in figure 1. Note that the can number is entirely arbitrary in this plot. From figure 1 one can see that the mass of a single USO is roughly 3 grams. Also note that there are jumps of two USO masses at about 40 and 46. The next step would be to assign n to each group of canisters: the first three would be $n = 1$, the next three would be $n = 2$, the next five would be $n = 3$, and so on. Students must be cautious at the jumps previously mentioned: there are four canisters for which $n = 10$, but the next group of five canisters corresponds to $n = 12$, rather than $n = 11$.

Figure 2 shows can mass versus n. The slope is the mass of a single USO.

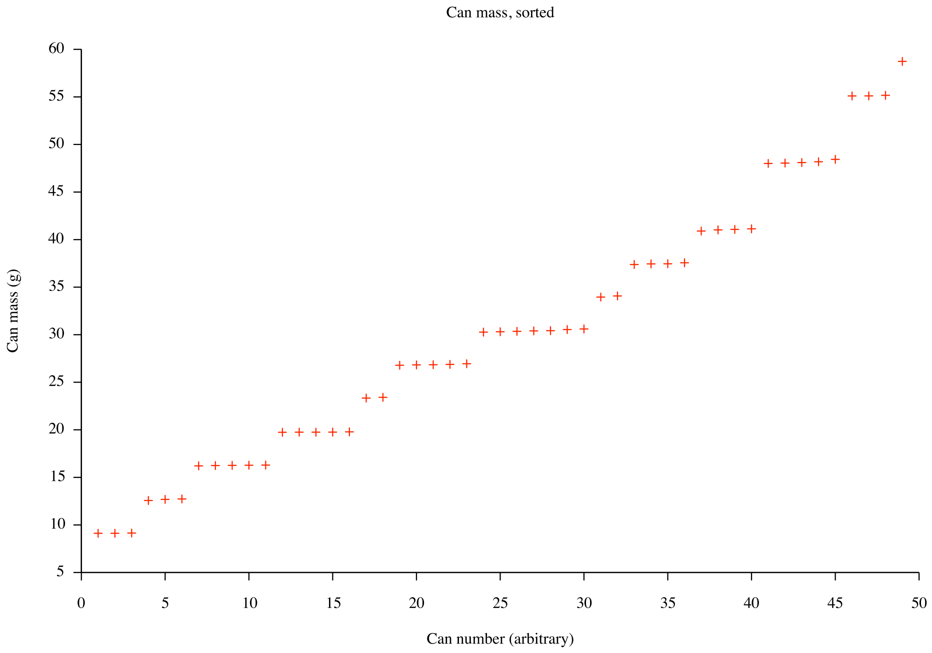

Figure 1: Milli-Can canister mass, sorted by increasing mass.

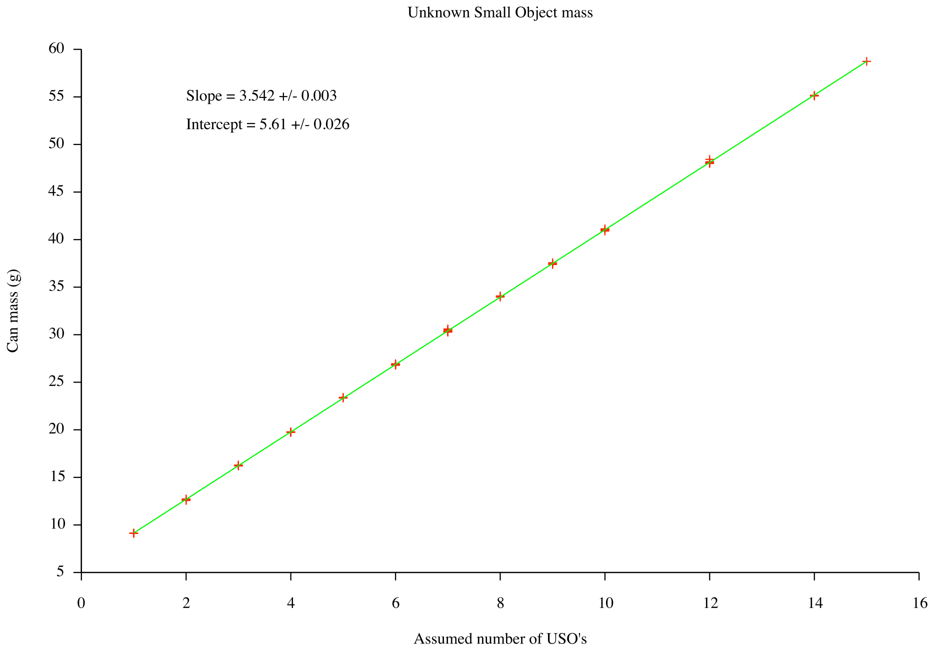

Figure 2: Linear plot, showing USO mass

Bibliography

[1] Franklin Miller Jr. Two kinds of electron? *The Physics Teacher*, 45(4):210–216, April 2007.

[2] R. A. Millikan. On the elementary electrical charge and the avogadro constant. *Phys. Rev.*, 2(2):109–143, Aug 1913.

[3] R. A. Millikan. A re-determination of the value of the electron and of related constants. *Proceedings of the National Academy of Sciences of the United States of America*, 3(4):231–236, April 1917.