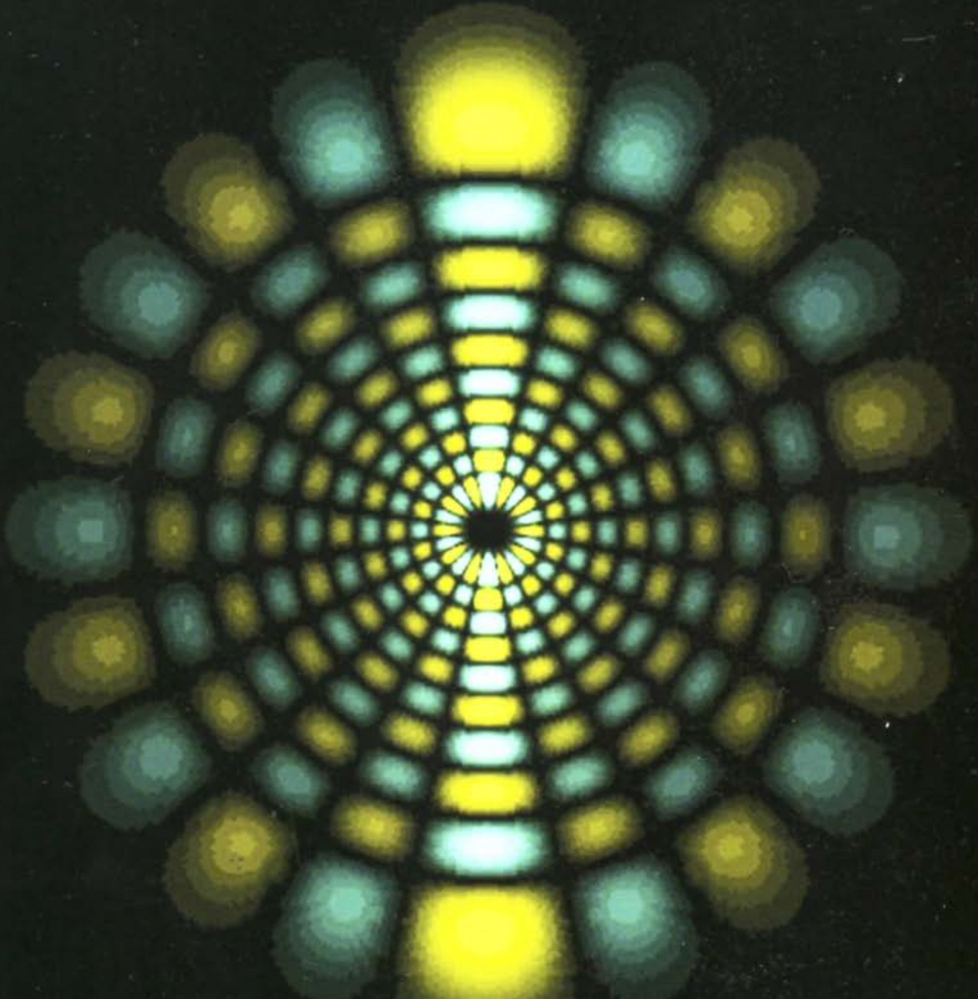
PHYSLET® QUANTUM PHYSICS

An Interactive Introduction



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CD ROM Included

Library of Congress Cataloging-in-Publication Data
Belloni, Mario.
Physlet® quantum physics: an interactive introduction / Mario Belloni, Wolfgang Christian, Anne J. Cox.
p. cm.– (PH series in educational innovation)
Includes bibliographical references.
ISBN 0-13-101970-8
1. Quantum theory–Computer-assisted instruction–Textbooks. 2. Quantum theory–Problems, exercises, etc. I. Christian, Wolfgang. II. Cox, Anne J. III. Title. IV. Prentice Hall series in educational innovation.
QC174.12.B445 2006
530.12'078'5–dc22 2005015232

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Pearson Prentice Hall
Pearson Education, Inc.
Upper Saddle River, New Jersey 07458

Printed in the United States of America
10 9 8 7 6 5 4 3 2

ISBN 0-13-101970-8

Pearson Education LTD., *London*
Pearson Education Australia PTY, Limited, *Sydney*
Pearson Education Singapore, Pte. Ltd
Pearson Education North Asia Ltd, *Hong Kong*
Pearson Education Canada, Ltd., *Toronto*
Pearson Educacion de Mexico, S.A. de C.V.
Pearson Education - Japan, *Tokyo*
Pearson Education Malaysia, Pte. Ltd

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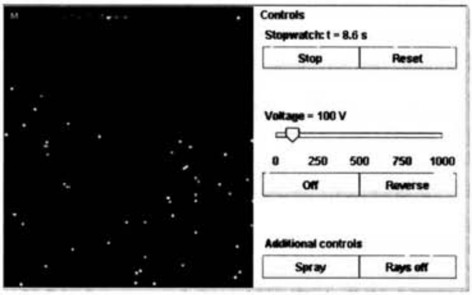
field (the y distance from its entry into the field to its exit). The force is given by $\mathbf{F} = q\mathbf{E}$ so the acceleration in the vertical direction is qE/m and the acceleration in the horizontal direction is zero. Therefore, from basic mechanics,

$$y = 1/2(qE/m)t^2 \quad \text{and} \quad x = vt\,, \tag{4.5}$$

and since you cannot measure the time in the animation (just as Thomson could not measure the time the electron was in the field), combine the two equations to solve for the deflection of y for electrons traversing a distance x and determine the value of q/m. There is not any way, in this experiment, to get a value for the mass or the charge independently. Why?

4.5 EXPLORING THE MILLIKAN OIL DROP EXPERIMENT


Stopwatch: t = 8.6 s

Voltage = 100 V

FIGURE 4.5: A simulation of the Millikan oil drop experiment The little circles represent oil drops with different size and therefore differing amounts of charge The view is as seen in a microscope.

J. J. Thomson's experiment (Section 4.4) resulted in a value for e/m (the ratio of the charge of the electron to the charge of the mass), but it took the Millikan's oil drop experiment to determine the value of the charge on the electron. This animation is a virtual version of Millikan's experiment.[3] The experiment was based on balancing forces: the downward gravitational force on an oil drop with the upward electric force up on the (ionized) oil drop. Below is a schematic of the apparatus. The sprayer releases ionized oil drops into the apparatus. The oil drops fall and enter a region where they can be seen through the microscope. Turning on the applied voltage provides a force that can, if adjusted correctly, exactly balance the gravitational force on the drop.

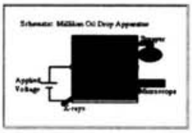


FIGURE 4.6: A schematic of the Millikan oil drop experiment

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[3] This Open Source Physics applet was written by Slavo Tuleja.

In the animation, push the "spray" button to spray a group of drops into the virtual apparatus where it is as if you are looking through the microscope (the grid lines are separated by 0.1 mm). Note that each individual drop falls (in the animation, the drops move vertically up because the microscope lens produces an inverted image) at a constant rate (no acceleration). This is because the drops are falling in air where the friction is not negligible and so they reach terminal velocity quickly.

You can "catch" one of the particles by turning on the voltage and adjusting it (push the "On" button and move the slider). The electric field produced (in the real experiment by two plates above and below the view of the microscope) provides a force in the opposite direction to the fall (rise in the animation). Balance a drop somewhere in the screen. Notice that the voltage you use to balance one drop, or several drops, does not balance the rest of the drops. The drops are not all the same size and do not have the same charge (just as in the real experiment).

"Catch" a drop by adjusting the voltage so that it stays still, at least on average. What are the small oscillations due to? (Hint: See Section 4.3.) Balancing the particles, then, you have set the electric force, qE (where q is the charge and E is the magnitude of the electric field) equal to the gravitational force, mg, so that

$$qV/d = mg \,, \tag{4.6}$$

where V is the voltage and d is the distance between the plates applying the voltage. Unfortunately, this still does not provide a value of the charge, q, independent of the mass, m. Record the value of the voltage to suspend this drop. Click the "Rays On" button. The rays you are turning on are X-rays that can change the charge of the drop (the X-rays ionize a drop by providing enough energy for an electron to leave). You will know the drop has changed charge when it starts to move from its *caught location* and head off screen. Now try to adjust the voltage to catch the drop again. Record this new voltage.

In this animation, as in Millikan's experiment, all the drops are not the same size.[4] This means that if you lose the drop you were trying to catch, you have to "spray" out some more drops and catch another one and keep it for a while. Record at least five (5) voltages required to suspend the same drop that you catch. Turn the "Rays On" and "Rays Off" as needed to change the charge of the drop and thus use different voltages to suspend the drop. Looking at the values, can you tell that the charge is quantized? For example, if you were able to record ten different measurements and your data table would look like the following (and it will not for this animation):

Voltage	980	-3030	2950	4060	8020	6970	-2020	5000	1050	6980	-1000

You might think that you could not suspend a drop with a voltage that was not essentially a multiple of 1000 V. If you took many more measurements (as

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[4] For more details on how Millikan carried out this experiment for measurements on multiple oil drops that were not of uniform size, see J. R. Taylor, C. D. Zafiratos, and Michael A. Dobson, *Modern Physics for Scientists and Engineers*, 2nd ed, Prentice Hall (2004), pp. 108-110 and Problem 3.45, pp. 122-123.

Millikan and his students did), you might argue that the reason that you cannot use a voltage of 1500 V to suspend a charge is that charge comes in discrete units. It is quantized. Look at your measurements for the voltage required to suspend one drop. Do they all (within your errors) have a common factor? What is it? Would you conclude, as Millikan did, that the charge is quantized? Explain.

Once a charge was balanced, Millikan could then find the charge on the electron by turning off the field and determining the terminal velocity of the drop. He did this by timing how long it took the charge to fall a set distance (like across ten grid units in the animation). The terminal speed, v, of a falling drop in a fluid is given by

$$v = 2r^2\rho g/9\eta\,, \tag{4.7}$$

where r is the radius of the drop, ρ is the density of the drop (in Millikan's case it was oil), and η is the viscosity of the fluid (air in this case). By measuring v, he could find the mass of the oil drop since $m = (4/3)\pi r^3\rho$, and then finally, having m and knowing the electric field, he could calculate the charge.

Catch another drop (or use the same one). Record the voltage necessary to hold it steady. Then, turn the field off, and use the stop watch in the animation to record the time for the particle to fall (to rise as seen in the microscope) across a set number of grid lines. Do this a couple of times with the same drop and determine the terminal velocity of this drop. In this animation, the drops are made out of oil with a density of 875 kg/m^3 and they are falling in air with a viscosity of 7.25×10^{-6} N·s/m^2. The spacing between the plates across which the voltage is applied is 6 mm. Calculate the radius of the drop you caught. From this, determine the charge on the drop. How many excess electrons does it have (or how many electrons have been removed from it)?

4.6 THOMSON MODEL OF THE ATOM

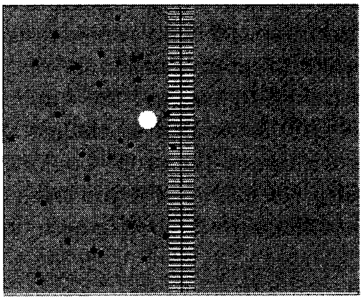

FIGURE 4.7: An alpha particle moving to the right colliding with electrons to simulate alpha particles traveling through a Thomson-like atom.

Once the view of matter as composed of atoms was on sound experimental and theoretical footing, the questioning then focused on the structure of atoms. Atoms were neutral, but contained negatively charged particles, electrons that were too light (5.5×10^{-4} amu) to constitute the mass of the atom (the lightest atom,