Electron 1 is accelerated from rest through a potential difference of 100 V.

Electron 2 is accelerated from rest through a potential difference of 200 V.

By how much is the de Broglie wavelength of electron 1 larger than that of electron 2

Using $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}}$ Prof. Becker calculated that $\lambda_1 = 2\,\lambda_2$. Was he correct?

(A) Yes (B) No

$\lambda_1 = \sqrt{2}\lambda_2$ is the correct answer

de Broglie wavelength

Consider the following particles:

- electron A with kinetic energy of 1 eV
- electron B with kinetic energy of 1 keV
- proton C with kinetic energy of 1 eV

Order the (de Broglie) wavelengths of these particles?

$$\lambda = \frac{h}{p} \quad \text{and} \quad k = \frac{p}{\hbar}$$

(A)A = C > B (B) A > B = C

(C) A > B > C (D) A = B = C

(E) Some other order

Student is asked to calculate the deBroglie wavelength of an electron with energy of 100 eV. The student uses:

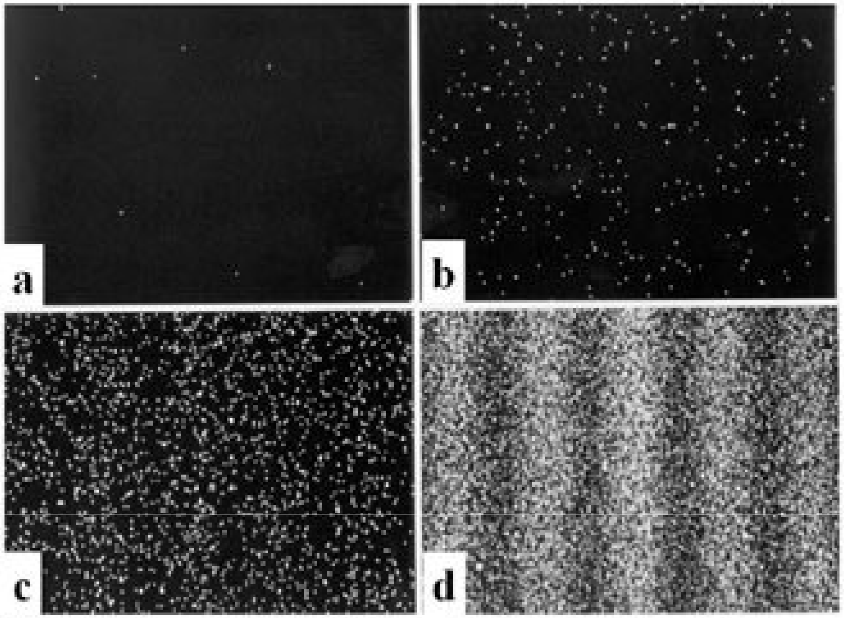
$$\lambda = \frac{h}{\sqrt{2mE}} = \frac{4.14\times10^{-15}\,\mathrm{eV\cdot s}}{\sqrt{2\times\left(9.11\times10^{-31}\,\mathrm{kg}\right)\times\left(100\,\mathrm{eV}\right)}}$$

and types the numbers in the calculator to get the answer for the wavelength in nm. Why is the answer incorrect?

The units do not work out! Therefore, the result will be incorrect.

*Advice: If you use in the formula mass (in kg), then change the energy value from eV to Joules and use the value for the Planck's constant in J*s.*

Double slit experiments with electrons



Single-electron Build-up of Interference Pattern

1964: Claus Jönsson

Am. J. Phys. **42**, 4 (1974)

1976: Merli, Missiroli and Pozzi

Am. J. Phys. **44**, 306 (1976)

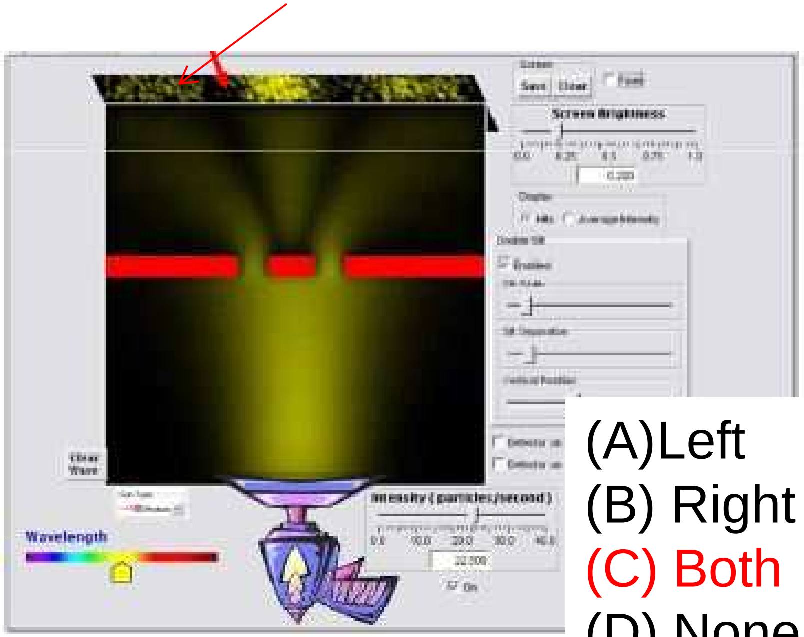
1989: Tonomura et al.

Am. J. Phys. **57**, 117 (1989)

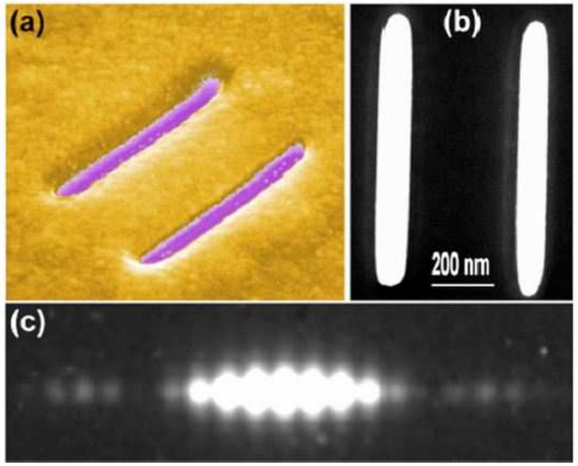
Think about the following observations/questions:

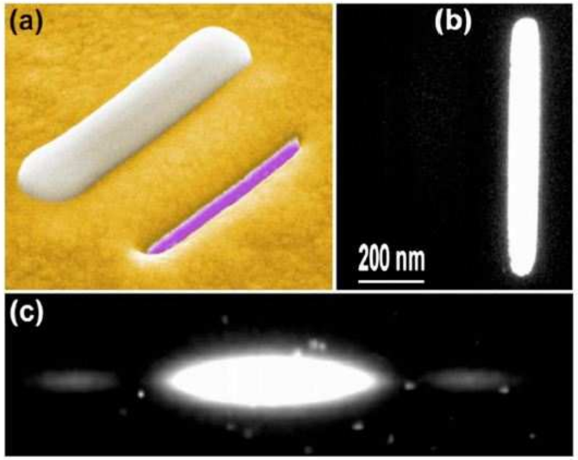
- For each electron you see a single light flash. What does this tell you about the nature of the electron?
  → particle feature, does not split
- Can you predict where the next light flash will be? What does this mean? → randomly, but more likely at certain positions

Which slit did this electron go through?



(A)Left
(B) Right
(C) Both
(D) None
(E) Either left or right

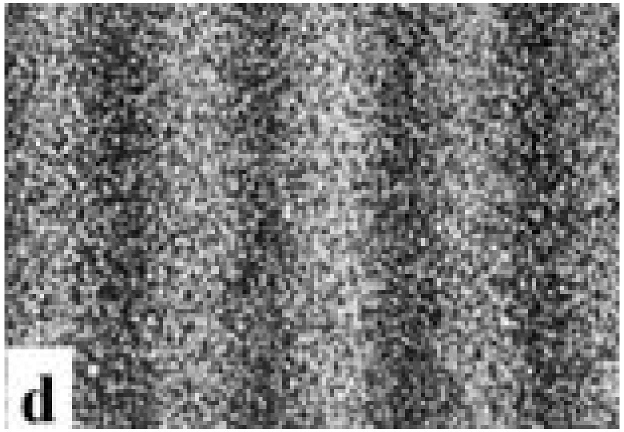




Slits are 83 nm wide and
spaced 420 nm apart

S. Frabboni, G.C. Gazzadi, and G. Pozzi, Nanofabrication and the realization of Feynman's two-slit experiment, Applied Physics Letters **93**, 073108 (2008).

*Note: The sum of two single-slit diffraction patterns is **not** the double slit diffraction pattern. This shows that we cannot consider in the double-slit experiment that the electrons have past either through the left or through the right slit. We are left with the conclusion that the electron has passed through both slits. This is in disagreement with our understanding of a particle from classical mechanics -> we will need to think about probabilities!*



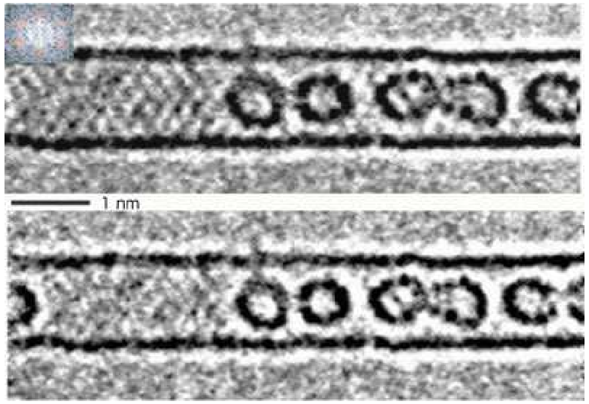
Summary so far:

- Individual light flashes, never two flashes at same time
  → particle feature

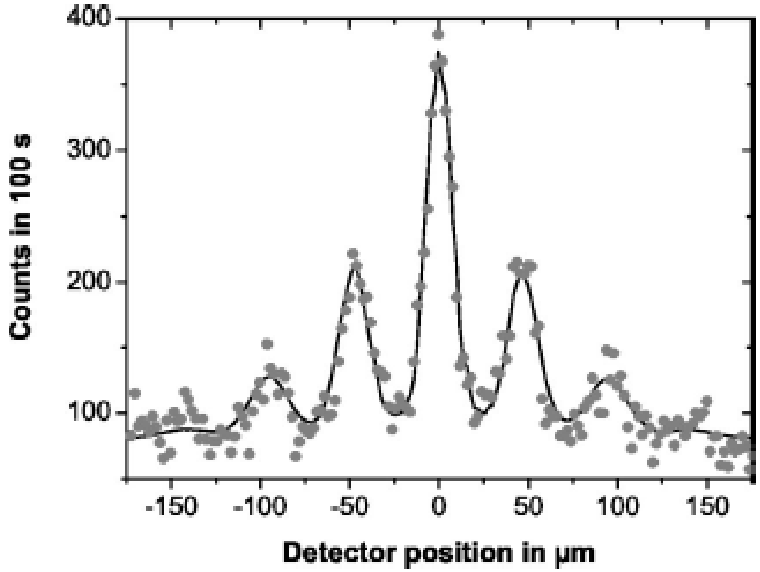
- Light flashes appear randomly with pattern
  → wave feature, probabilistic, must be property of electron

Double slit experiment with C_{60} molecules

C_{60}: The smallest natural soccer ball



C_{60} in carbon nanotube
(Electron microscope image)



Double slit diffraction pattern

What is the de Broglie wavelength of C_{60}?

Nairz, Arndt and Zeilinger,
Am. J. Phys. **71**, 319 (2003)