Millikan's Oil Drop Experiment as a Smartphone Lab?

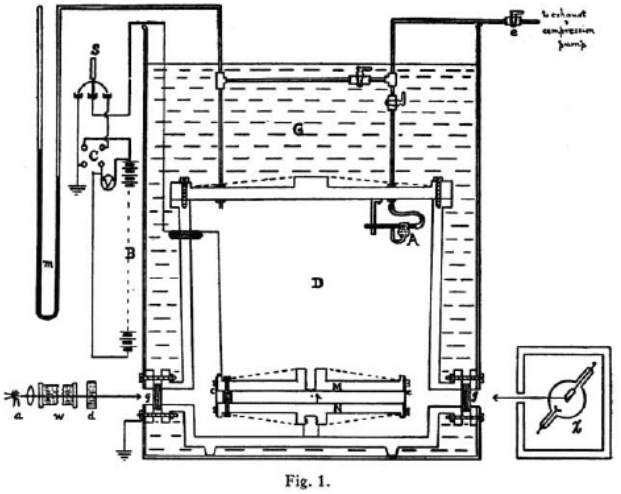

Fig. 1.

???

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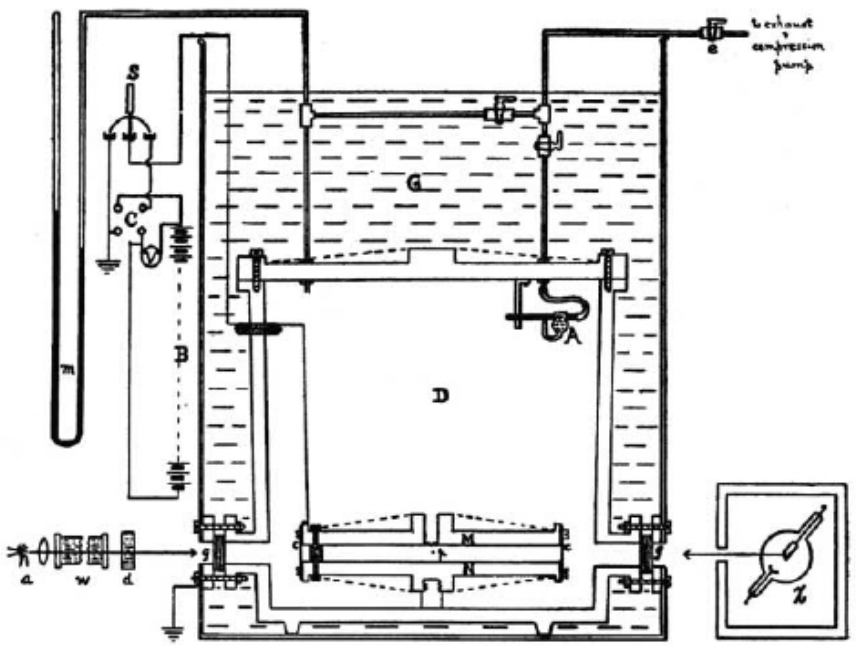
Centenary College of Louisiana
2024 AAPT Winter Meeting

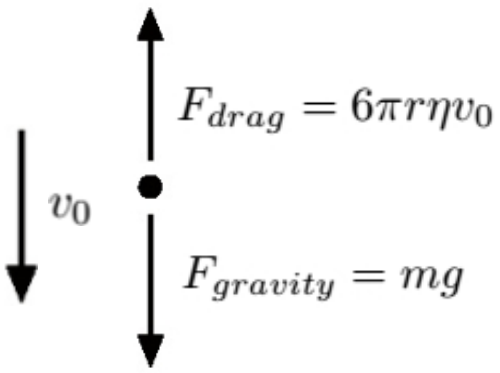
Outline

- Review: Millikan’s oil drop experiment
- Review: Smartphone lab tools
- Smartphone implementation details
  - Connecting the smartphone to a microscope
  - Extracting velocity data from videos
  - Plotting the charge calculations in a histogram
- Additional points of interest
- Conclusion

Millikan's Oil-Drop Experiment

- Classic experiment intended to demonstrate charge quantization
- Oil droplets fall at speed v_0 once drag matches gravitational force





$$-F_{gravity} + F_{drag} = 0$$

$$-\frac{4}{3}\pi r^3 \rho g + 6\pi r\eta v_0 = 0$$

Millikan's Oil-Drop Experiment

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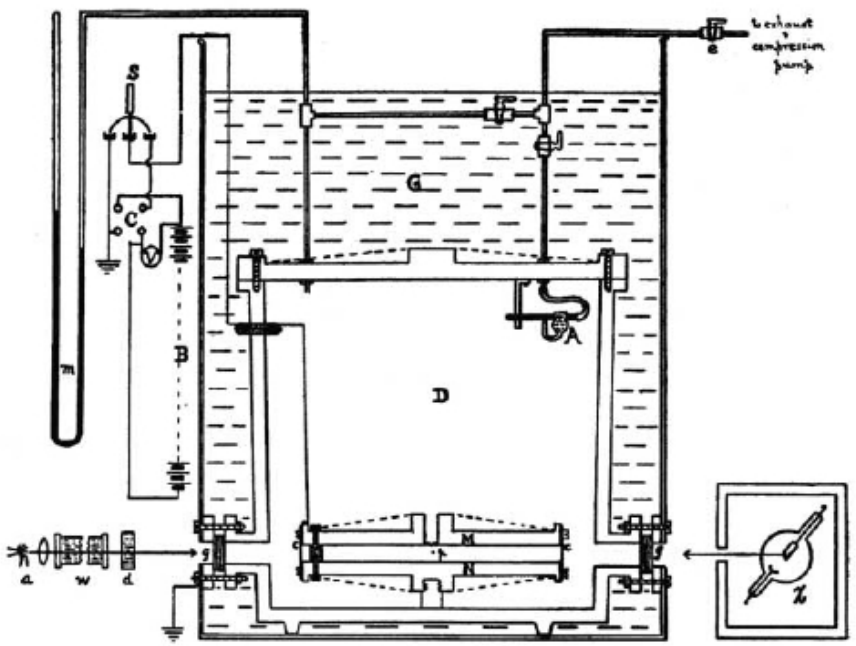

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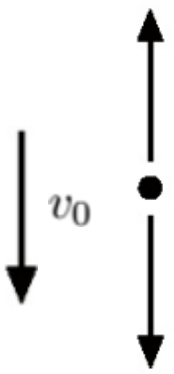


$$-F_{gravity} + F_{drag} = 0$$

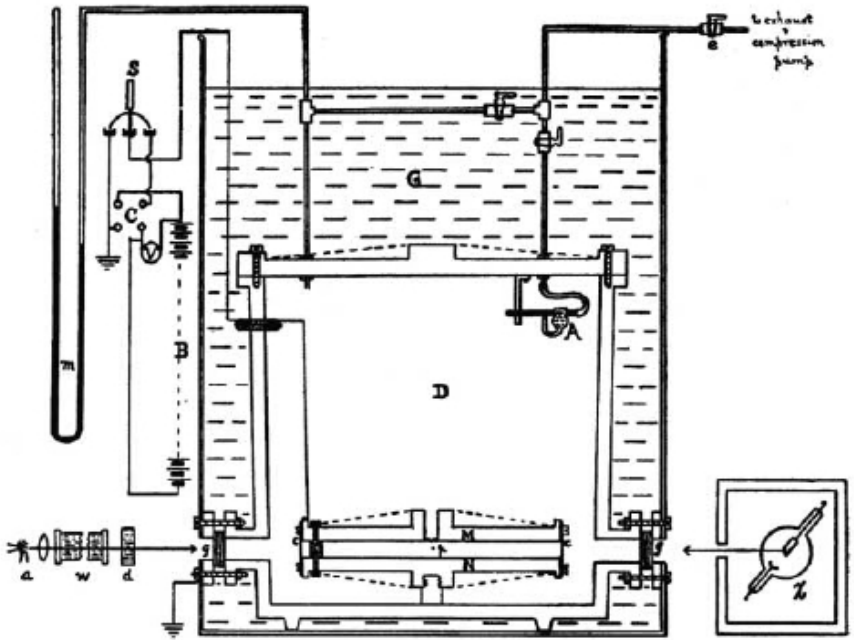
$$-\frac{4}{3}\pi r^3 \rho g + 6\pi r\eta v_0 = 0$$

- Allows us to find the droplet radius

$$r = \sqrt{\frac{9\eta v_0}{2\rho g}}$$

Millikan's Oil-Drop Experiment

- Classic experiment intended to demonstrate charge quantization
- Oil droplets move with velocity v_1 in a downward electric field with magnitude $E = \Delta V/\Delta d$ between the charged plates



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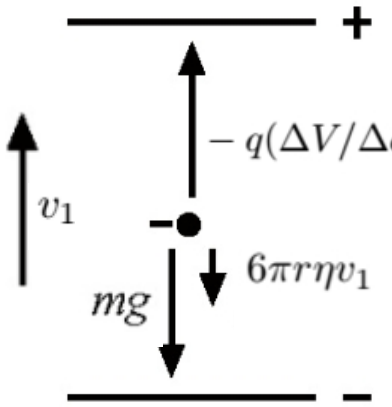
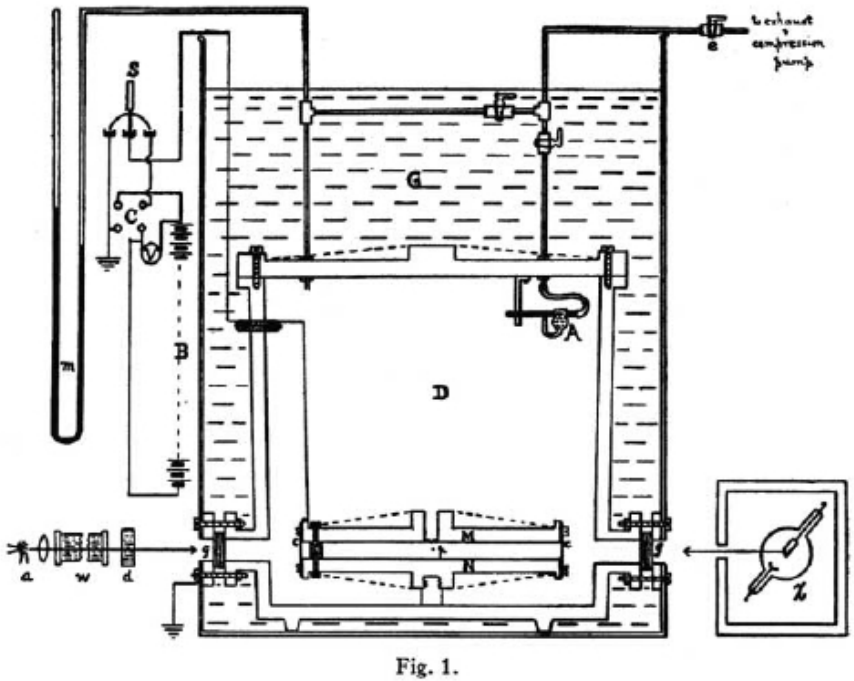


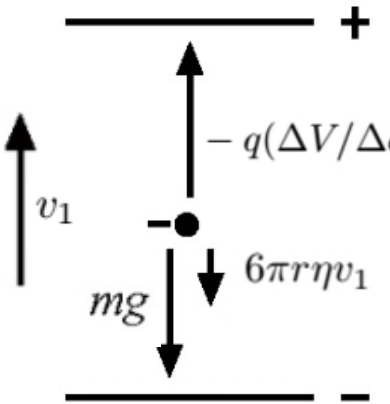
$$-F_{gravity} + F_{drag} - F_{electric} = 0$$

$$-\frac{4}{3}\pi r^3\rho + 6\pi r\eta v_1 - q(\Delta V/\Delta d) = 0$$

Millikan's Oil-Drop Experiment

- Classic experiment intended to demonstrate charge quantization
- Oil droplets move with velocity v_1 in a downward electric field with magnitude $E = \Delta V/\Delta d$ between the charged plates





$$-F_{gravity} + F_{drag} - F_{electric} = 0$$

$$-\frac{4}{3}\pi r^3\rho + 6\pi r\eta v_1 - q(\Delta V/\Delta d) = 0$$

- Allows us to solve for the charge

$$q = -\frac{\Delta d}{\Delta V}\left(6\pi r\eta v_1 + \frac{4}{3}\pi r^3\rho g\right)$$

Extra Details

- Droplet radii are small relative to inter-atomic spacing in air, so viscosity needs correction

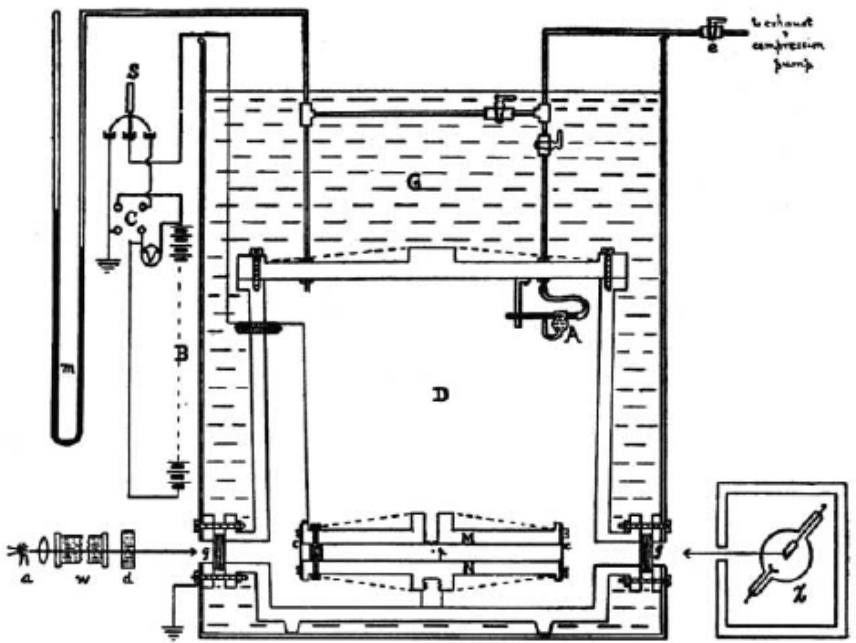


Fig. 1.

$$\eta' = \eta_0 \left(\frac{1}{1 + (b/pr')} \right)$$

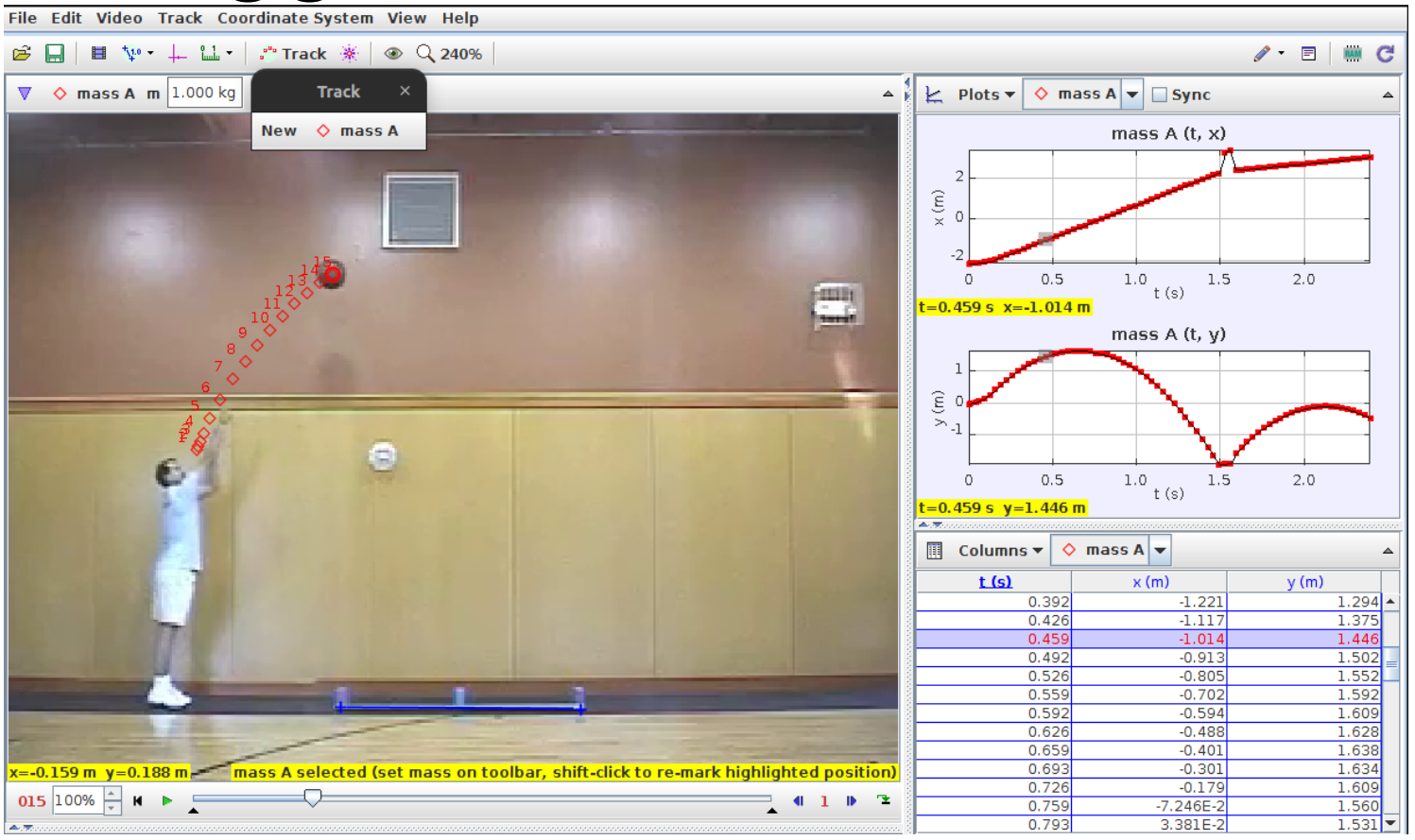
- This corrects the radius…

$$r' = \sqrt{\frac{9\eta_0 v_0}{2\rho g} + \left(\frac{b}{2p}\right)^2} - \frac{b}{2p}$$

- ...and the charge

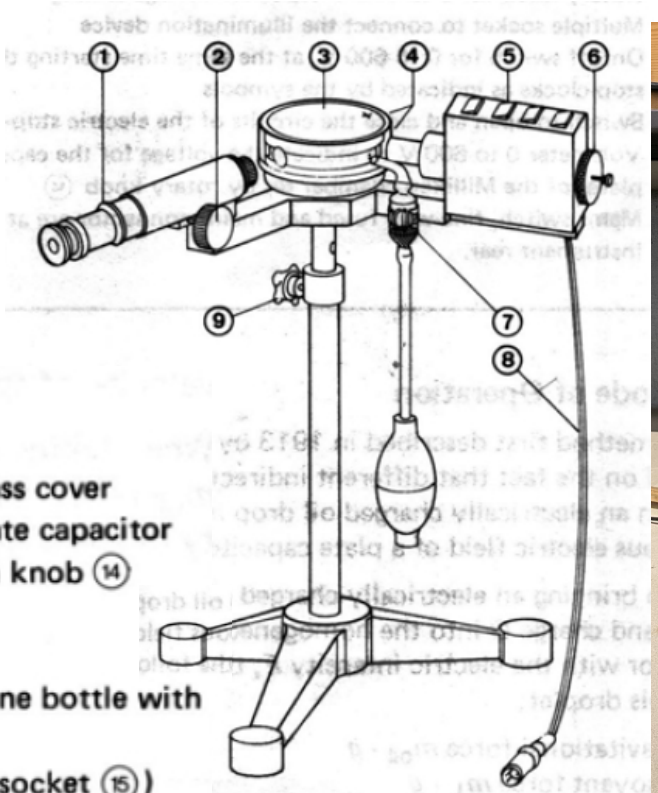
$$q' = -\frac{\Delta d}{\Delta V}\left(6\pi r \eta' v_1 + \frac{4}{3}\pi r'^3 \rho g\right)$$

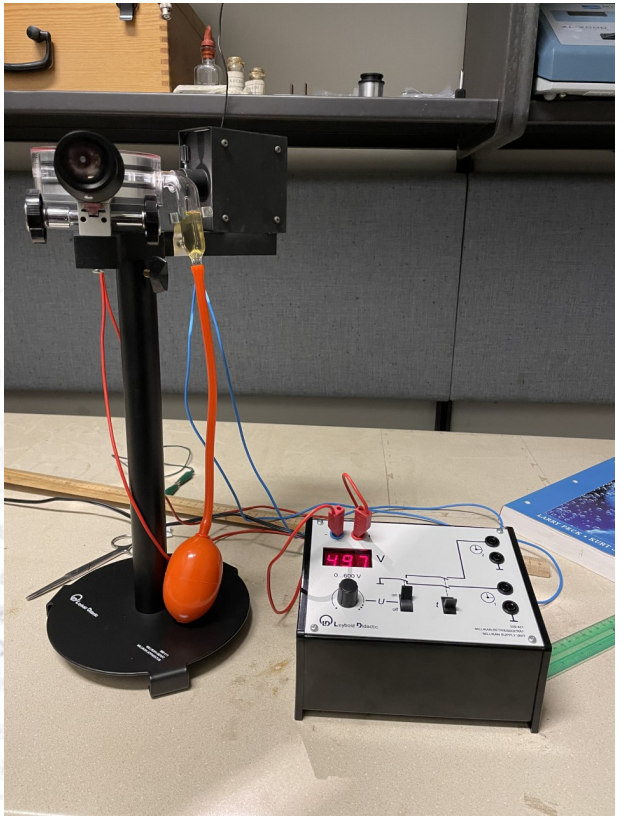
Smartphone as physics tool – LoggerPro, Tracker, etc.



Basic Instrument: LD Didactic 559411

- Similar operation to models from Pasco, TEL-atomic, 3B Scientific, etc.



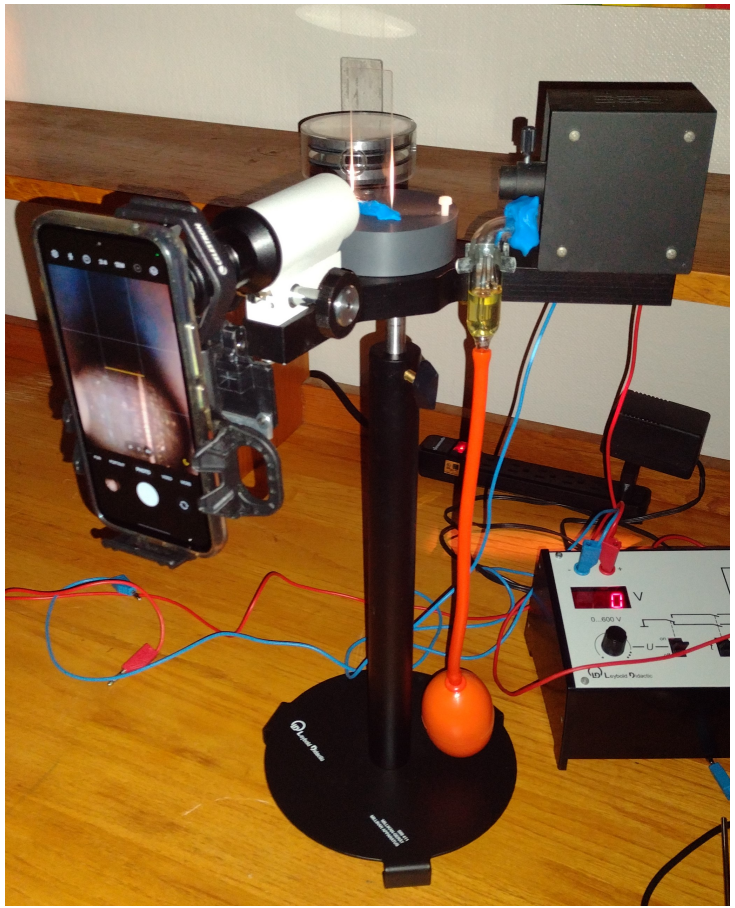


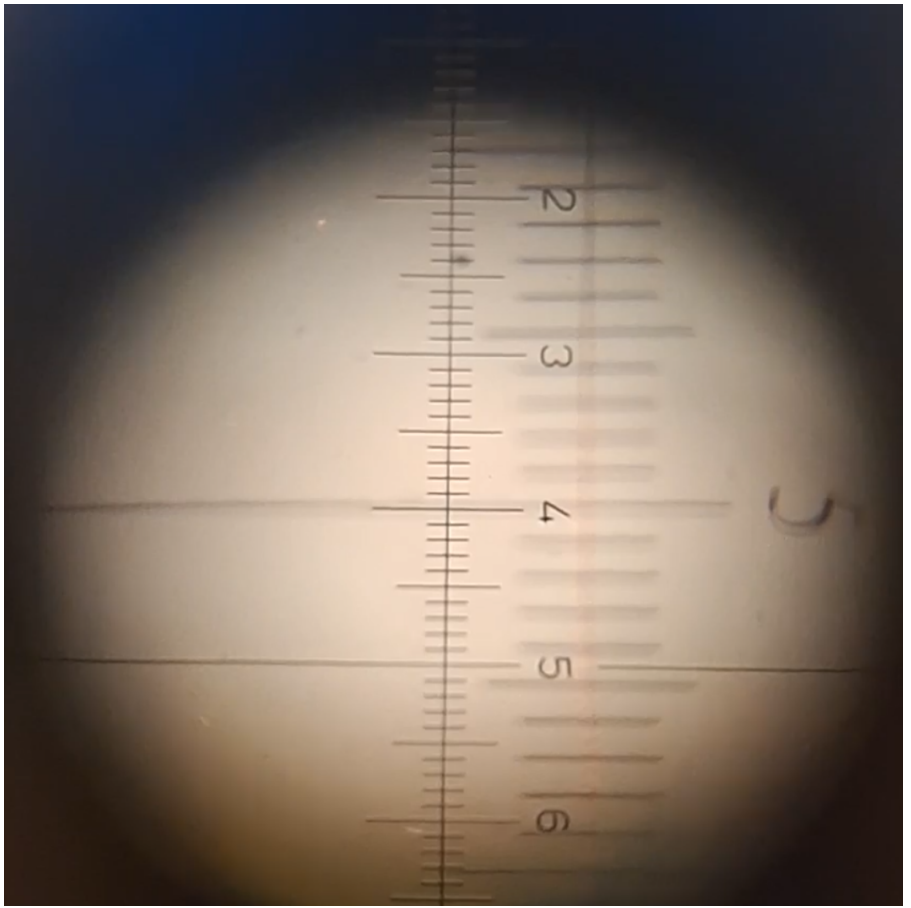
① Measuring microscope with micrometer eyepiece
② Knurled knob for microscope adjustment
③ Millikan chamber (plate capacitor) with acrylic glass cover
④ Socket pair to connect the d. c. voltage for the plate capacitor (can be tapped from socket pair ⑪, adjustable via knob ⑭)
⑤ Illumination device
⑥ Knurled knob for lamp adjustment
⑦ Oil atomizer with rubber ball in resilient holder (one bottle with oil included in scope of delivery)
⑧ Connecting cable for lamp voltage (from multiple socket ⑮)
⑨ Screw for height adjustment (to adapt the microscope to the eye level of the experimenter)

Celestron NexGO Universal Smartphone Adapter

- This adapter adjusts up/down and right/left – but three-axis adjusting adapters available

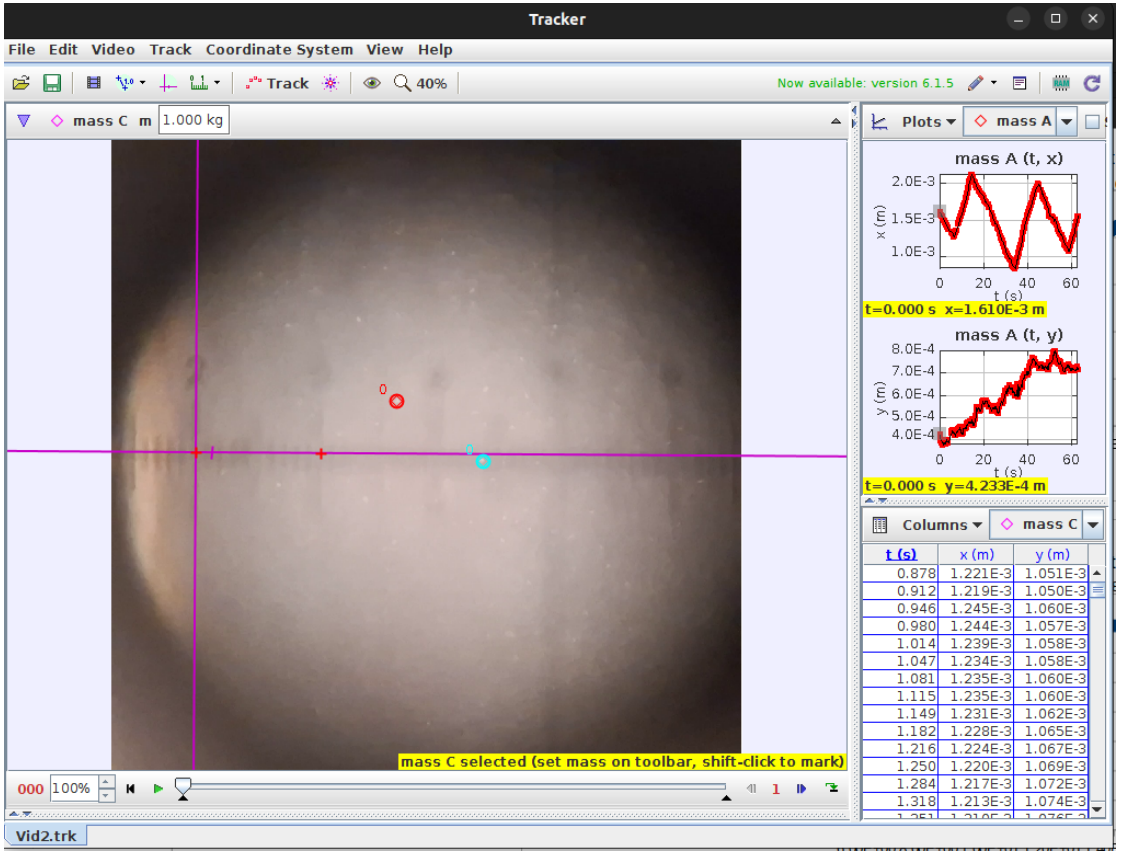
1. Measure the magnification





2. Take videos, extract the data

- 20 videos, ~1 minute each
- 18 videos with usable data
- 44 droplets were tracked overall



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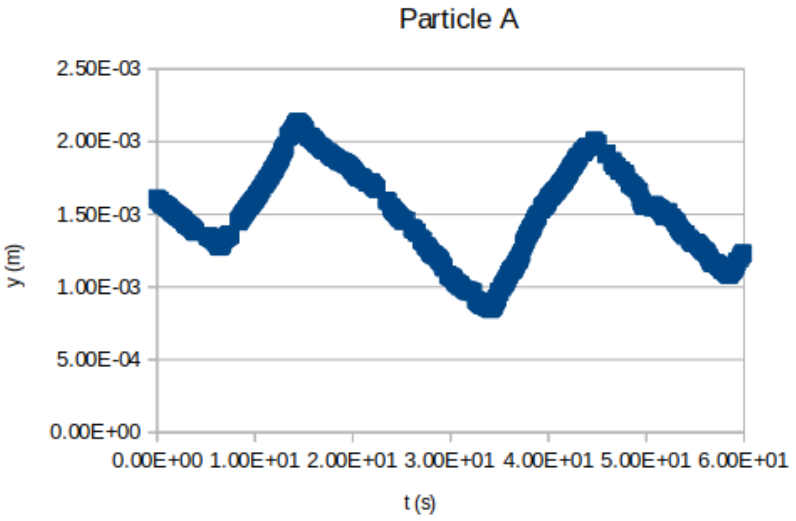
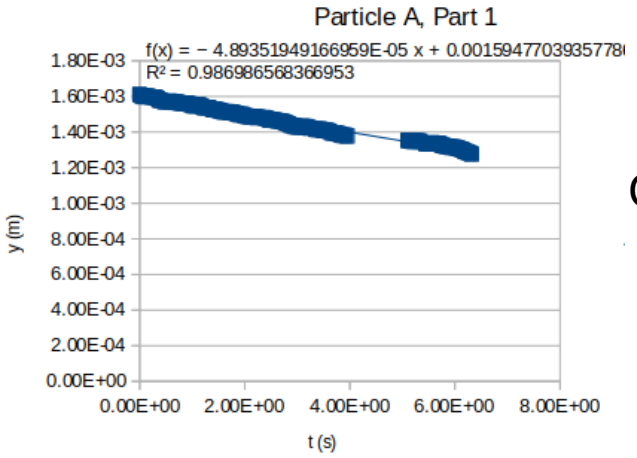
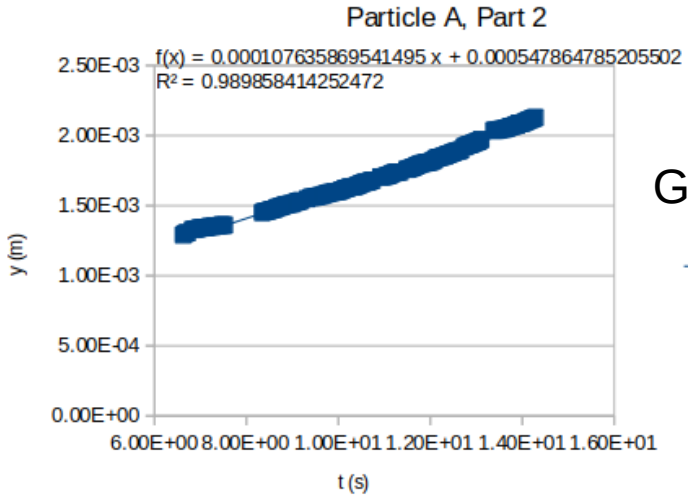




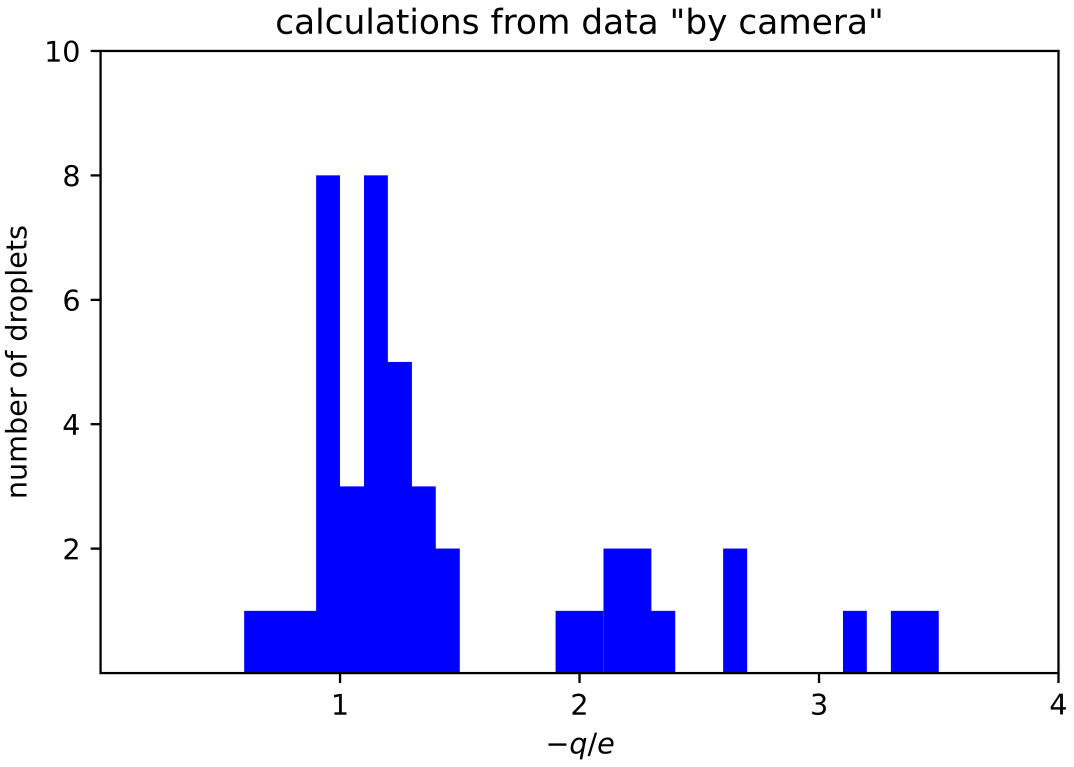
Gives us v_0



Gives us v_1

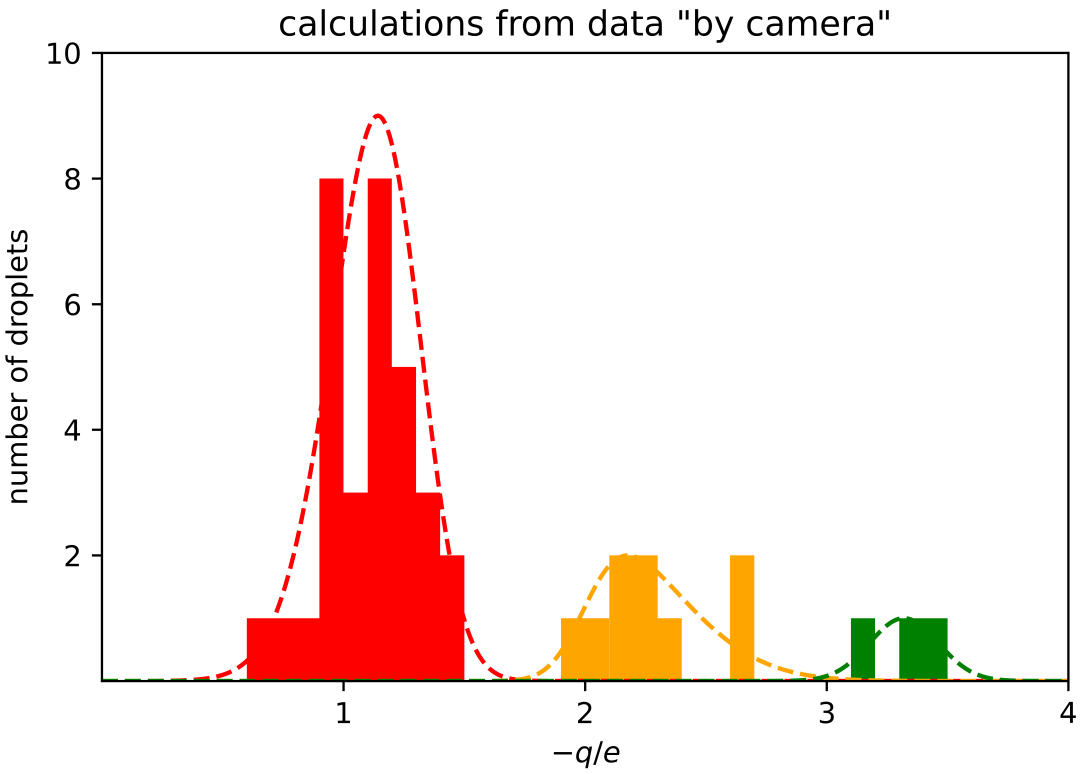
3. Repeat, and plot the charge

- Show the data as a histogram



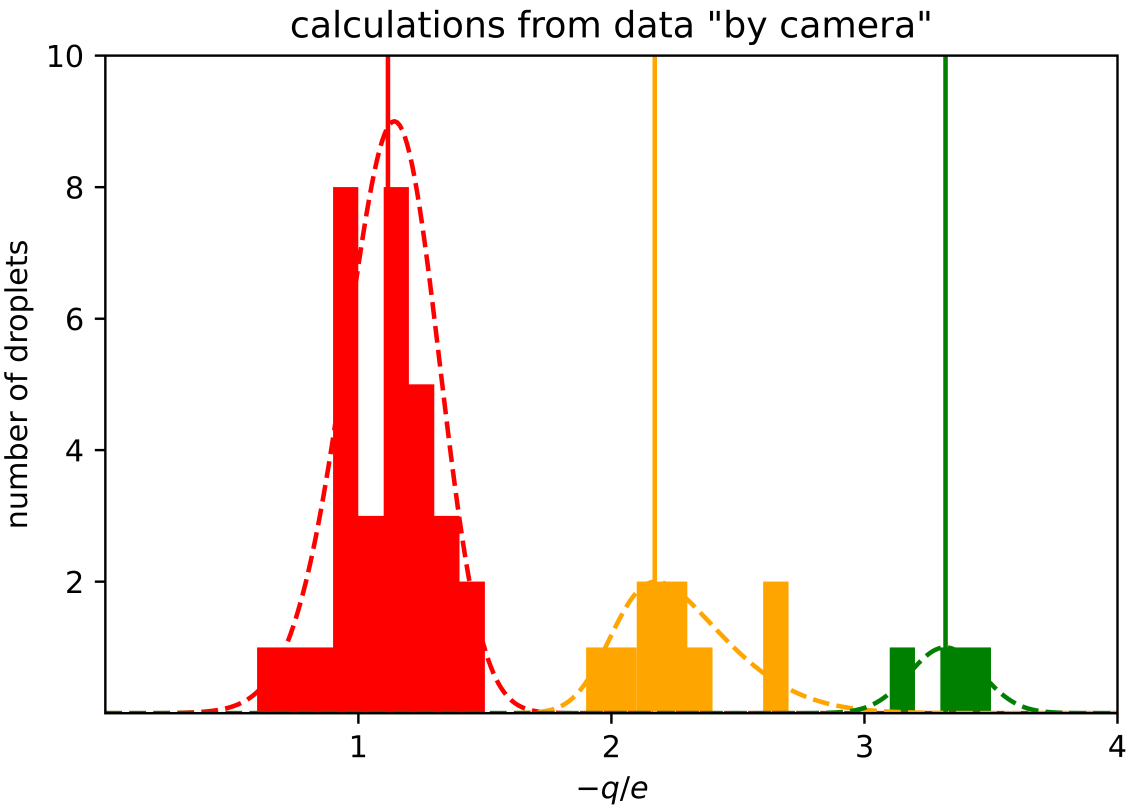
3. Repeat, and plot the charge

- Show the data as a histogram
- Group the bins into categories



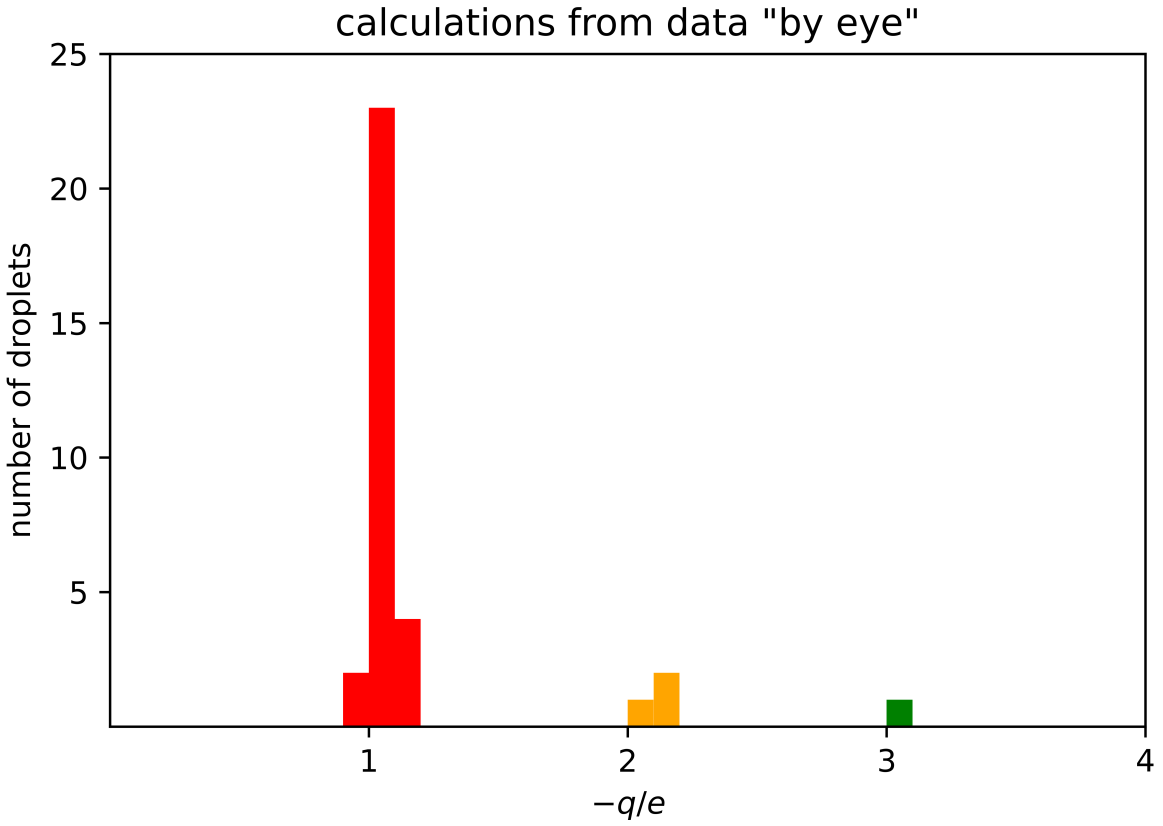
3. Repeat, and plot the charge

- Show the data as a histogram
- Group the bins into categories
- Category averages:
  - q_1 = -1.12 e
  - q_2 = -2.17 e
  - q_3 = -3.32 e



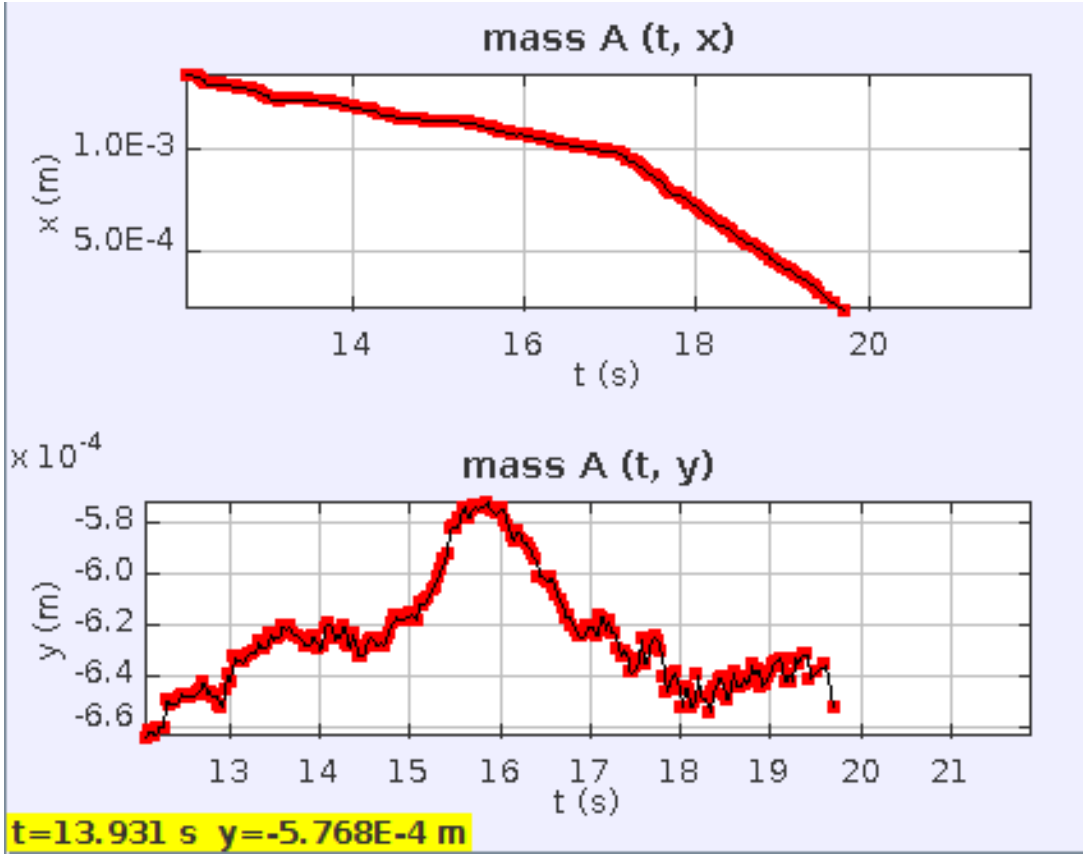
A Big Caveat

- Here is data taken “by eye” with the same instrument (33 droplets overall)
- Harder to get data, but easier to interpret
  - q_1 = -1.05 e
  - q_2 = -2.10 e
  - q_3 = -3.09 e



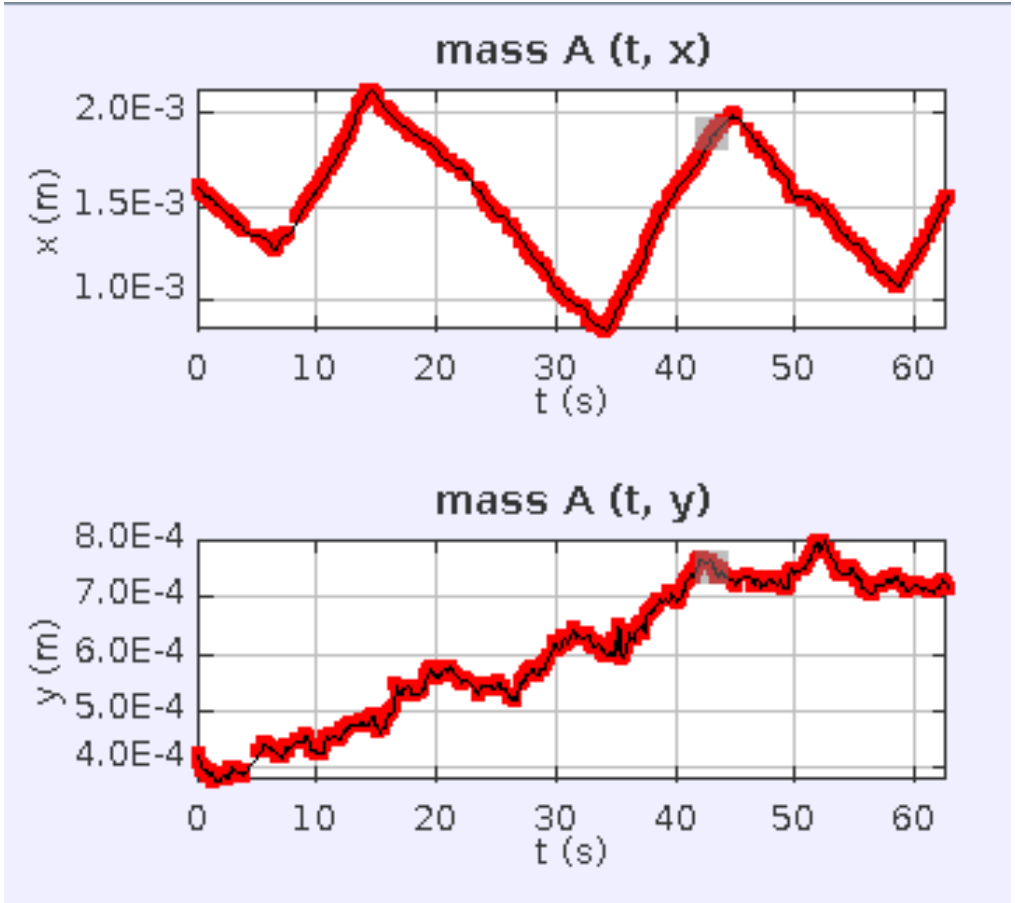
Two points of interest

- 1. This method allows droplets to be tracked even if they do not change direction



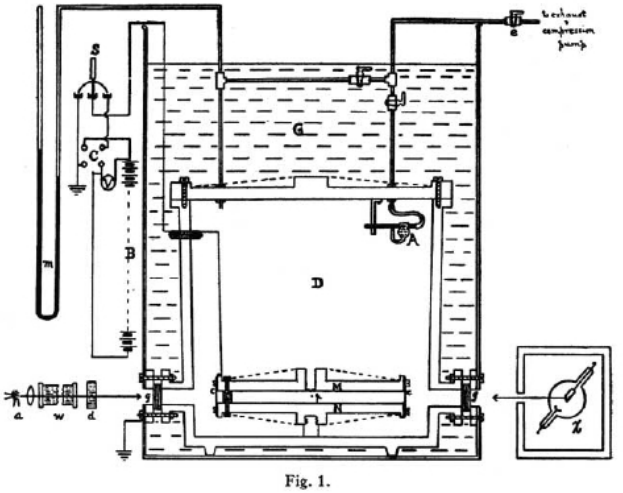
Two points of interest

- 1. This method allows droplets to be tracked even if they do not change direction
- 2. This method also allows “random walk” aspects of lateral motion to be tracked



Conclusion

- Possible to use smartphone for data collection in microscope/telescope
- Maintaining quantitative accuracy without an internal scale marker is hard
- Opens up possibilities for other undergraduate labs



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