Electricity – Designing a Voltmeter

Review

Lecture # 7

Physics 2BL

Winter 2011

CAPE Evaluation

- Important for fine tuning of the course
- Making changes
- Giving feedback

The Four Experiments

- **Determine the average density of the earth**

Weigh the Earth, Measure its volume

  – Measure simple things like lengths and times

  – Learn to estimate and propagate errors

- **Non-Destructive measurements of densities, inner structure of objects**

  – Absolute measurements *vs.* Measurements of variability

  – Measure moments of inertia

  – Use repeated measurements to reduce random errors

- **Construct and tune a shock absorber**

  – Adjust performance of a mechanical system

  – Demonstrate critical damping of your shock absorber

- **Measure coulomb force and calibrate a voltmeter.**

  – Reduce systematic errors in a precise measurement.

Outline

- Experiment 4 – electrical forces
- Torsional pendulum
- Uncertainties
- Review for final

Purpose

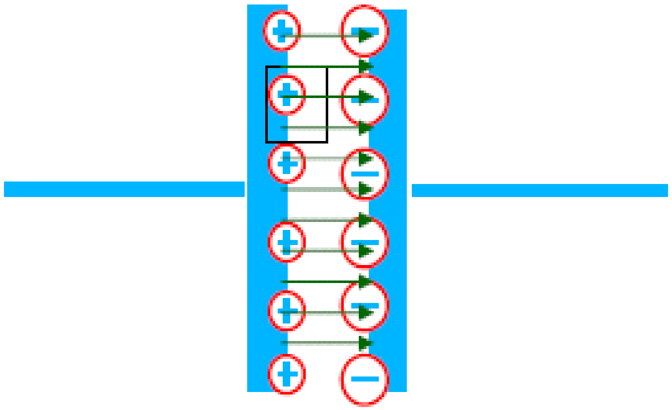
- Design a means to measure electrical voltage through force exerted on charged object

Method

- Use Torsional pendulum
- Balance forces, balance torques

Experiment #4: Parallel Plate Capacitor

We suggest the use of a parallel plate capacitor rather than charged spheres



$$E = \frac{Q}{A\varepsilon_0}$$ from Gauss's Law

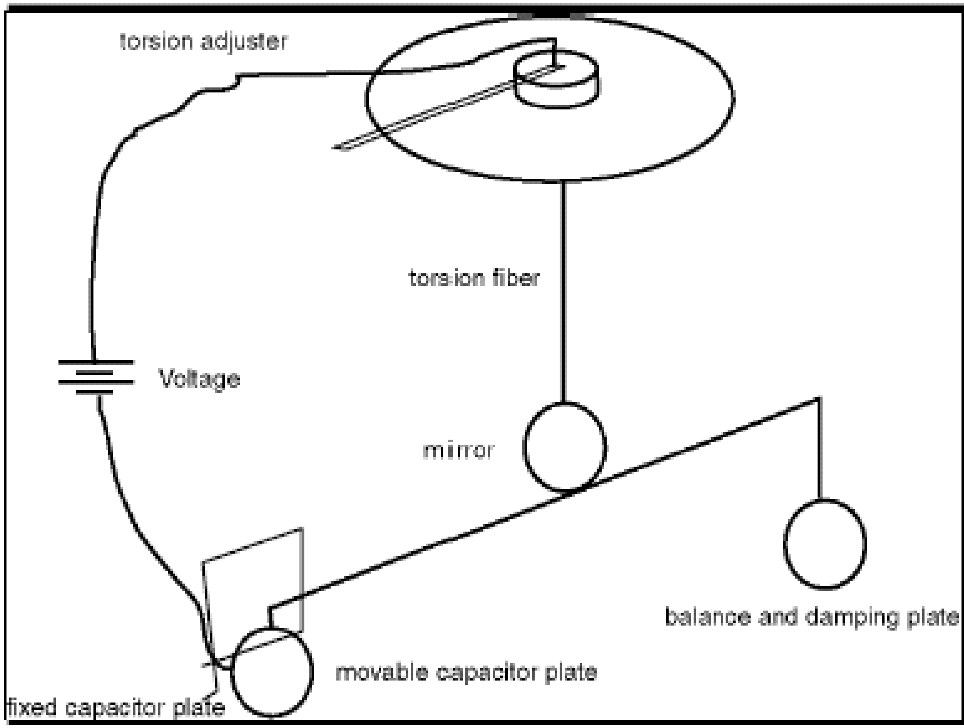
$$V = Ed = \frac{Qd}{A\varepsilon_0}$$ voltage difference

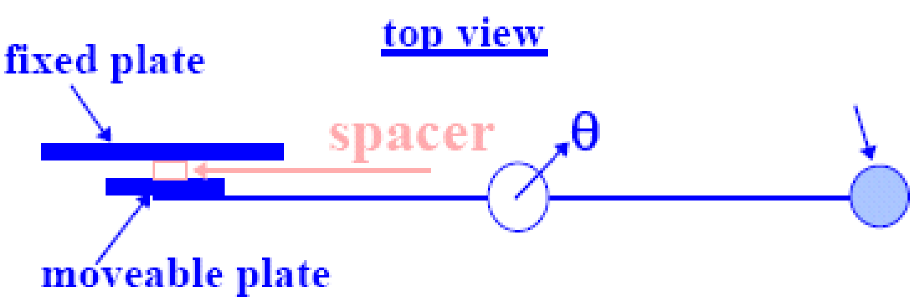
$$F = \frac{1}{2}EQ = \frac{1}{2}\frac{Q^2}{A\varepsilon_0} = \frac{1}{2}\frac{A\varepsilon_0}{d^2}V^2$$ the force

$$F = \frac{1}{2}\frac{\left(A = 3\ \mathrm{cm}^2\right)\left(\varepsilon_0 = 8.8\times10^{-12}\ \frac{\mathrm{F}}{\mathrm{m}}\right)}{\left(d = 0.1\ \mathrm{cm}\right)^2}\left(V = 1000\ \mathrm{V}\right)^2 = 1.2\times10^{-3}\ \mathrm{N}$$

The weight of 0.1 g.

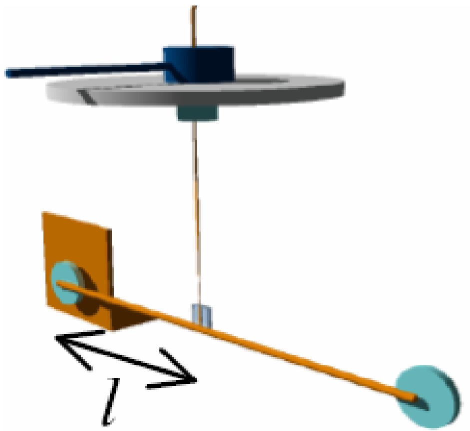
Calibrate Voltmeter





- Set up the apparatus.
- Keep table dry.
- Make the plates parallel for spacer in contact.
- Measure the spacer.
- Measure κ.
- Find Voltage that just causes plates to move apart.
- Try calibration at about 1000 Volts.
- Now get several measurements at lower voltage.
- Water must be stable.
- Move slowly.
- Protect your apparatus from air currents.
- Estimate errors

Measure κ using Torsional Pendulum



$$F = \kappa\theta / l$$

l - Distance from the suspension to the disk is measured with a ruler

θ - Deflection angle is measured with a protractor

How do we measure the torsion constant κ?

Torsional oscillations $$T = 2\pi\sqrt{\frac{I}{\kappa}}$$

$$\kappa = \left(\frac{2\pi}{T}\right)^2 I$$

I - Moment of inertia

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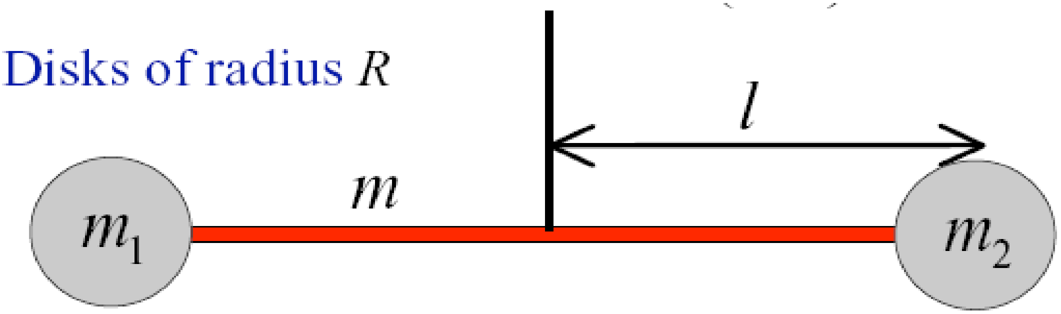
$$\varepsilon_\kappa = \sqrt{(\varepsilon_I)^2 + (2\varepsilon_T)^2}$$

$$\sigma_\kappa = \kappa * (\varepsilon_\kappa)$$

Moment of Inertia

Disks of radius R



You want to weigh the support beam and disks separately

Error Propagation…

$$I = \frac{1}{3} m l^2 + (m_1 + m_2) l^2 + (m_1 + m_2)\frac{R^2}{4}$$

rod — parallel axis theorem — disks - CM

$$\sigma_I = \sqrt{[(\delta I/\delta m)\sigma_m]^2 + [(\delta I/\delta m_1)\sigma_{m1}]^2 + [(\delta I/\delta m_2)\sigma_{m2}]^2 + [(\delta I/\delta l)\sigma_l]^2 + [(\delta I/\delta R)\sigma_r]^2}$$

Error in Moment of Inertia

$$I = 1/3(ml^2) + (m_1+m_2)\, l^2 + (m_1+m_2)R^2/4$$

$$\sigma_I = \sqrt{[(\delta I/\delta m)\sigma_m]^2 + [(\delta I/\delta m_1)\sigma_{m1}]^2 + [(\delta I/\delta m_2)\sigma_{m2}]^2 + [(\delta I/\delta l)\sigma_l]^2 + [(\delta I/\delta R)\sigma_r]^2}$$

$$\delta I/\delta m = 1/3(l^2)$$

$$\delta I/\delta m_1 = l^2 + R^2/4 = \delta I/\delta m_2$$

$$\delta I/\delta l = 2/3(ml) + 2(m_1+m_2)l$$

$$\delta I/\delta R = 1/2(m_1+m_2)R$$

Equilibrium Positions

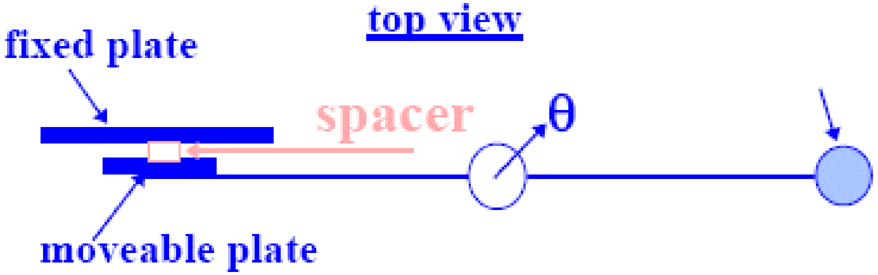
$F = \frac{1}{2}\frac{A\varepsilon_0}{d^2}V^2$ electrostatic attraction

Fl torque resulting from the electrostatic force

$k\theta$ torque resulting from the fiber

hold separation between the capacitor plates fixed as the voltage between them is increased by twisting the top end of the fiber

$$V = d\sqrt{\frac{2k\theta}{lA\varepsilon_0}}$$



Error Propagation

$$V = d\sqrt{2\kappa\theta/lA\varepsilon_0}$$

$$\varepsilon_V = \sqrt{(\varepsilon_d)^2 + (\varepsilon_\kappa/2)^2 + (\varepsilon_\theta/2)^2 + (\varepsilon_A/2)^2 + (\varepsilon_l/2)^2}$$

$$\sigma_V = V * (\varepsilon_V)$$

Review

Determination of errors from measurements

- Two types – random (statistical) and systematic
- Random errors – intrinsic uncertainty (limitations)
- Can be determined from multiple measurements
  - Mean and standard deviation, standard deviation of the mean

Propagation or uncertainties through formulas

- Simple formula for adding two terms (a=b+c)
- Simple formula for multiplying two terms (a=b*c)
- General formula for g(x,y,z)

Final Overview

Will be given basic physics equations

Need to know how to use them (labs)

Understand significant figures and how to quotes values properly

Need to know basic error propagation formulas

Need to know Gaussian distributions

mean, standard deviation, standard deviation of the mean

Final Overview

Know how to determine t-values
extract probability information from those values

Understand rejection of data – Chauvenet’s principle

Know how to calculate weighted averages

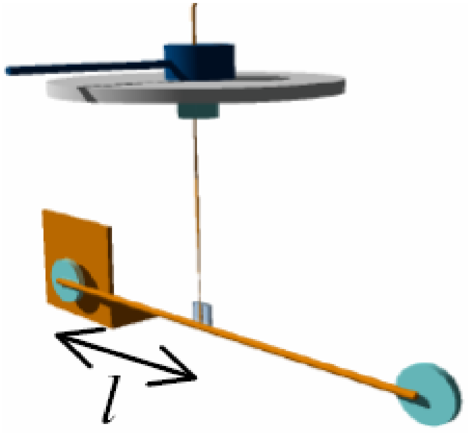
Let’s do an example

Example Question

You want to determine the torsional constant for the wire you used in the last experiment. You do this by measuring the period of oscillation. You make 5 measurements of 15.1 s, 13.2s, 14.4 s, 15.4 s and 14.6 s. What is the best value for the torsional constant κ with the proper number of significant figures and uncertainty. You also determined the moment of inertia to be (2420 ± 120) g cm^2.

Example Solution

(1) Draw diagram



(2) Identify given parameters

Given T values and I

(3) Write the equation(s) necessary to calculate κ

Torsional oscillations $T = 2\pi\sqrt{\frac{I}{\kappa}}$

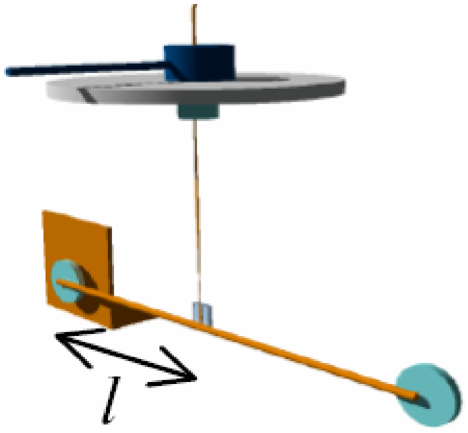
$$\kappa = \left(\frac{2\pi}{T}\right)^2 I$$

I - Moment of inertia

(4) Calculate best value for T

$$T_{best} = T_{ave} = 14.54 \text{ s}$$

Example Solution



(5) Calculate uncertainty in T

$$\sigma_T = 0.847 \text{ s}$$

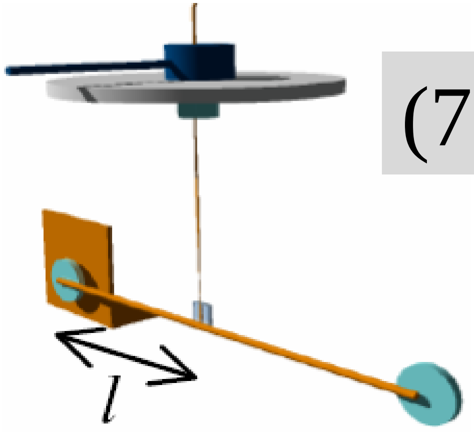
$$\sigma_{\bar{T}} = 0.424 \text{ s} = 0.4 \text{ s}$$

$$T_{best} = (14.5 \pm 0.4) \text{ s}$$

(6) Calculate κ from best values

$$\kappa = 4\pi^2 I/T^2 = 454.4 \text{ g cm}^2/\text{s}^2$$

Example Solution



(7) Calculate uncertainty for κ

$$\varepsilon_\kappa = \sqrt{(\varepsilon_I)^2 + (2\varepsilon_T)^2}$$

$$\varepsilon_\kappa = \sqrt{(120/2420)^2 + (2*0.4/14.5)^2}$$

$$\varepsilon_\kappa = \sqrt{(.0496)^2 + (.0552)^2}$$

Most significant source of uncertainty?

$$\varepsilon_\kappa = .07$$

$$\sigma_\kappa = \kappa * (\varepsilon_\kappa) = 30 \text{ g cm}^2/\text{s}^2$$

Thus, $\kappa = (450 \pm 30) \text{ g cm}^2/\text{s}^2$

Reminder

- Finish Experiment 4
- Last lecture - No more lectures
- Pre-final discussion section this Friday, March 4th
- Final on Monday 7-7:50pm