Physics (PHYS2500J): 1. Introduction

Xiao-Fen Li
Associate Professor, SJTU

Fall 2023

Contents

Ourselves

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TA: Mr. Leyan Zhang
Miss Xiruo Wang

Any questions are welcome at any time during the class!
Any critical opinions are welcome!

Contents

What we learn during the semester

- Electromagnetics
  - Electrostatics
    - Electric field, Gauss's law
    - Potential
    - Materials in electric field
    - Electric field energy
  - Steady current field
    - Ohm's law
    - Current density field, continuity equation
  - Magnetostatics
    - Lorentz force
    - Ampere's circuital law
    - Biot-Savart's law
    - Magnetic materials
  - Electro-magnetic induction
    - Faraday's law
    - Maxwell's displacement current
  - Circuits
  - EM wave
- (wave) optics
  - Light
    - Coherence
    - Interference
    - Polarization

We learn the electromagnetic field related phenomena.

What we learn during the semester

Electromagnetics

- Electrostatics
  - Electric field, Gauss's law
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- Circuits
- EM wave

(wave) optics

- Light
  - Coherence
  - Interference
  - Polarization

$$\vec{\nabla} \cdot \vec{E} = \rho / \epsilon_0$$

$$\vec{\nabla} \cdot \vec{B} = 0$$

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

And the mathematical way of describing and predicting them.

$$\vec{\nabla} \times \vec{B} = \mu_0 \left(J + \epsilon_0 \frac{\partial \vec{E}}{\partial t} \right)$$

What we do not learn in this class

Next step engineering classes

Electromagnetic field

Electrical engineering

Electronics

Fundamental class

Electromagnetics

Next step physics classes

Electrodynamics

Plasma physics

Magnetics

Next step knowledge

Dielectric material

Magnetic material

What we do not learn in this class

Optics is such a useful engineering class and a beautiful physics class!

Optics

Geometrical optics

Short wavelength, propagating in lines.

Wave optics / physical optics

Interference, diffraction, polarization…

Quantum optics / molecular optics

Interactions with matter: absorption, scattering, spectrum…

Fourier optics

Based on the convolution nature of light propagation, combining optics, mathematics and information theory.

Non-linear optics

Refraction index (polarization of dielectric) as a function of intensity.

Laser brought us many new aspects of optics:

Monochromatic:

scanning spectrums;

Coherent:

OCT;

Parallel:

pointing, (together with high Coherency) possible to focus to high intensity for fine/fast machining

What we do not learn in this class

Optics is such a useful engineering class and a beautiful physics class!

Optics

Geometrical optics

Short wavelength, propagating in lines.

Wave optics / physical optics

Discussing the EM wave nature of light, fundamental to all but geometrical optics

Quantum optics / molecular optics

Interactions with matter: absorption, scattering, spectrum…

Fourier optics

Based on the convolution nature of light propagation, combining optics, mathematics and information theory.

Non-linear optics

Refraction index (polarization of dielectric) as a function of intensity.

Laser brought us many new aspects of optics:

Monochromatic:

scanning spectrums;

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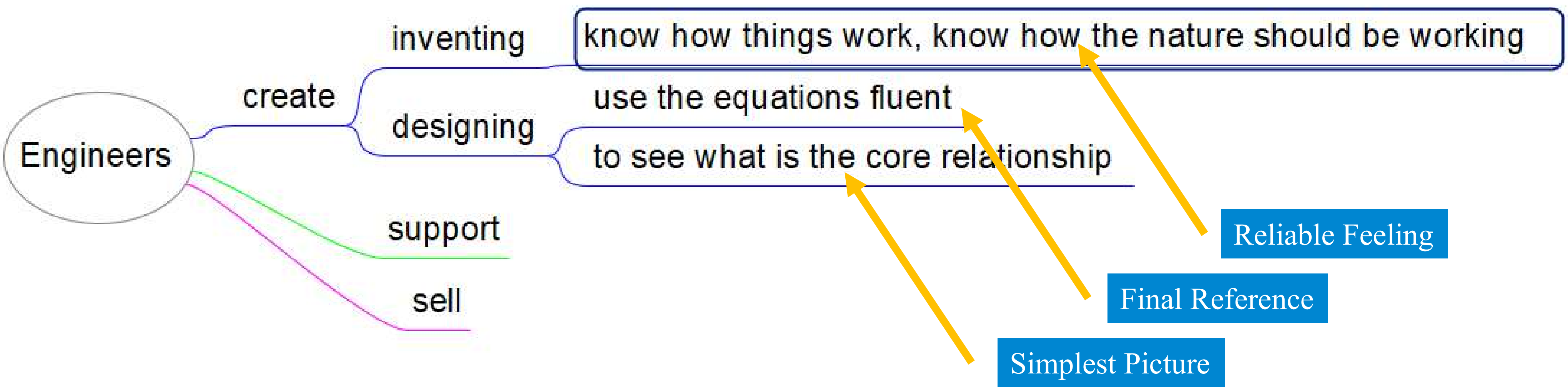
Why do we learn it AS PHYSICS?

Engineers create, support, and sell machines.

Barry Harvey



How do we learn it AS PHYSICS?

Reliable Feeling

Reliable: we have to doubt, to discuss (NOT DEBATE)

Feeling: we have to pay attention to 1. dimensions; 2. symmetries

Final Reference

Final: we have to pay attention to the assumptions

Reference: we have to remember where to find it rather than every equation

Simplest Picture

Simplest: we have to 1. remove the negligible; 2. pay attention to degrees of freedom

Picture: we have to see the physical meaning behind the letters in the equations

How do we learn it AS PHYSICS?

Reliable Feeling

Reliable: we have to doubt, to discuss (NOT DEBATE)

Discuss

Feeling: we have to pay attention to 1. dimensions; 2. symmetries

Dimensions

Symmetries

Final Reference

Final: we have to pay attention to the assumptions

Assumptions

Reference: we have to remember where to find it rather than every equation

Simplest Picture

DOF

Simplest: we have to 1. remove the negligible; 2. pay attention to degrees of freedom

Picture: we have to see the physical meaning behind the letters in the equations

Picture

The target of this course

To establish a solid foundation for engineering applications;
To get a feel of how things should be working, for future innovation. (And to know how to prove it);
To learn how to ask, instead of answering questions (And provide a way to answer the questions);

To learn how to discuss things with your fellow students;
To enjoy the wisdom of human;

To learn some useful tricks on the way, such as making plots with Matlab.

Why do we need a teacher?

~~He is clever~~

~~He is always right~~

Just because he is old!

He can tell you what (probably) happens in the future when you need the knowledge.

He can show you the (wrong) way to get to the correct understandings.

Most importantly, he makes a lot of mistakes so that you know you can do better.

TEXT BOOKS:

Hugh D. YOUNG, Roger A. FREEDMAN, *University Physics* (14th edition)

selected topics: David J. GRIFFITHS, *Introduction to Electrodynamics* (3rd edition)

Extended Readings (Necessary terms in Chinese)

电动力学，郭硕鸿，第三版，高等教育出版社

p3-p109，simple and clearly summarized useful information of electromagnetics

新概念物理：电磁学，赵凯华，陈熙谋，第二版，高等教育出版社

Deep thinking, good questions asked and answered

Contents

We grade, we do NOT judge

Grading Policy:

Coursework (including problems and quiz) (15%)

homework should be submitted on time (usually before the class next week, Monday's homework before Monday class, Thursday's work before Thursday class)

Participation (5%)

Take part in Class, as well as the discussion, ask or answer questions (asking questions is highly appreciated);

Mid-term Exam (40%)

Final Exam (40%)

extra (1%)

For those who is taking part in the Physics competition, and on a necessary base.

Did you learn the following contents?

1. Mechanical wave.
2. Differential vector calculus.

Physics (PHYS2500J), Unit 1 Electrostatics:
1. Coulomb’s law

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William Gilbert: The father of electrostatics

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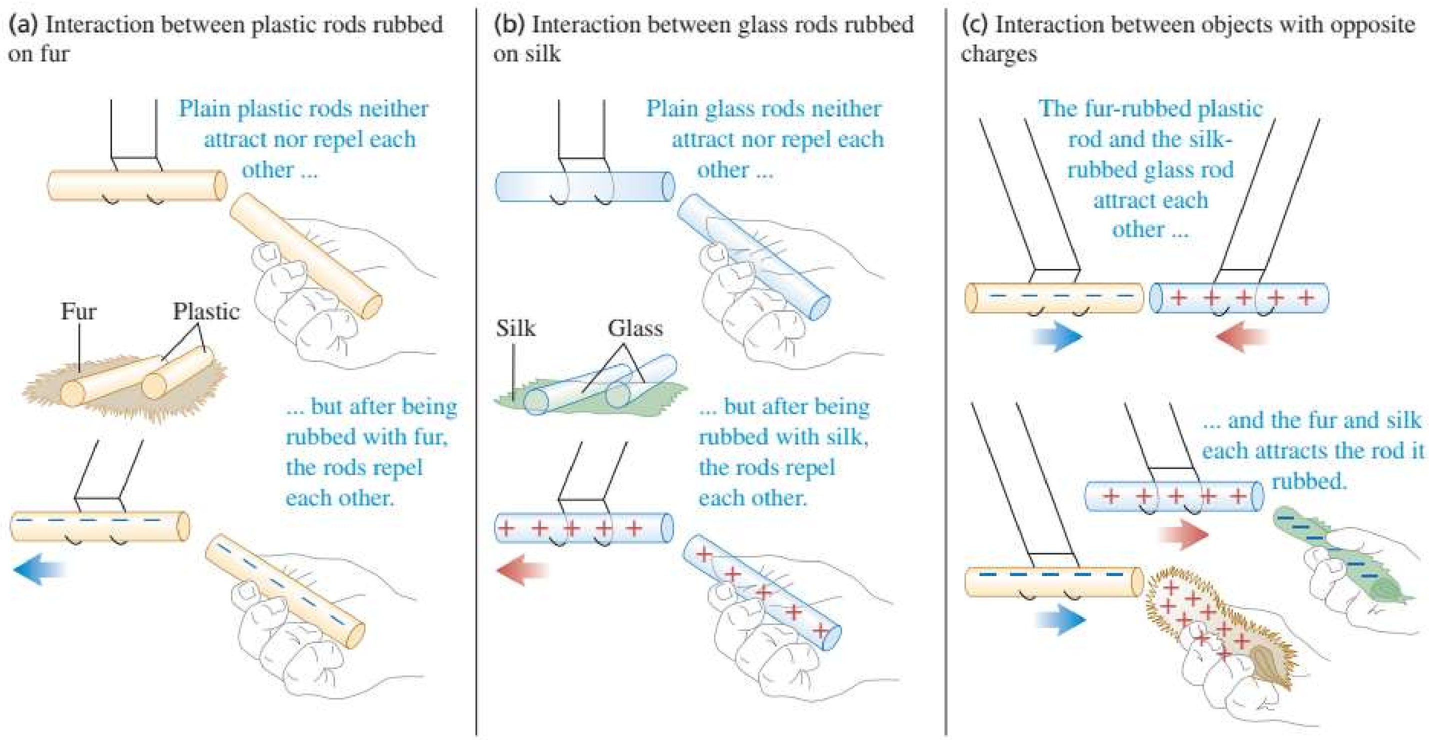
William Gilbert (1544-1603)

Royal (medical) doctor for Queen Elisabeth I

Started the word electricus, from Greek word ηλεκτρον (Elektron).

Sir Gilbert was first to make the case for differentiating between magnetic attraction and electrical attraction—static electricity—which later proved the foundation for future discoveries about electricity.
Sir Gilbert's used the word "electricus", meaning "like amber".

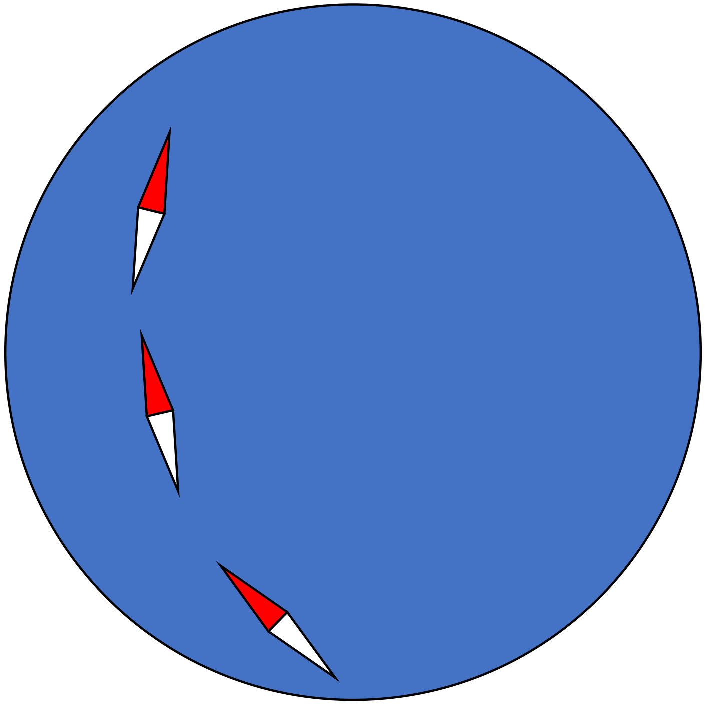

(a) Interaction between plastic rods rubbed on fur
Plain plastic rods neither attract nor repel each other ...
Fur
Plastic
... but after being rubbed with fur, the rods repel each other.
(b) Interaction between glass rods rubbed on silk
Plain glass rods neither attract nor repel each other ...
Silk
Glass
... but after being rubbed with silk, the rods repel each other.
(c) Interaction between objects with opposite charges
The fur-rubbed plastic rod and the silk-rubbed glass rod attract each other ...
... and the fur and silk each attracts the rod it rubbed.

William Gilbert: The father of electrostatics

William Gilbert (1544-1603)

Royal (medical) doctor for Queen Elisabeth I

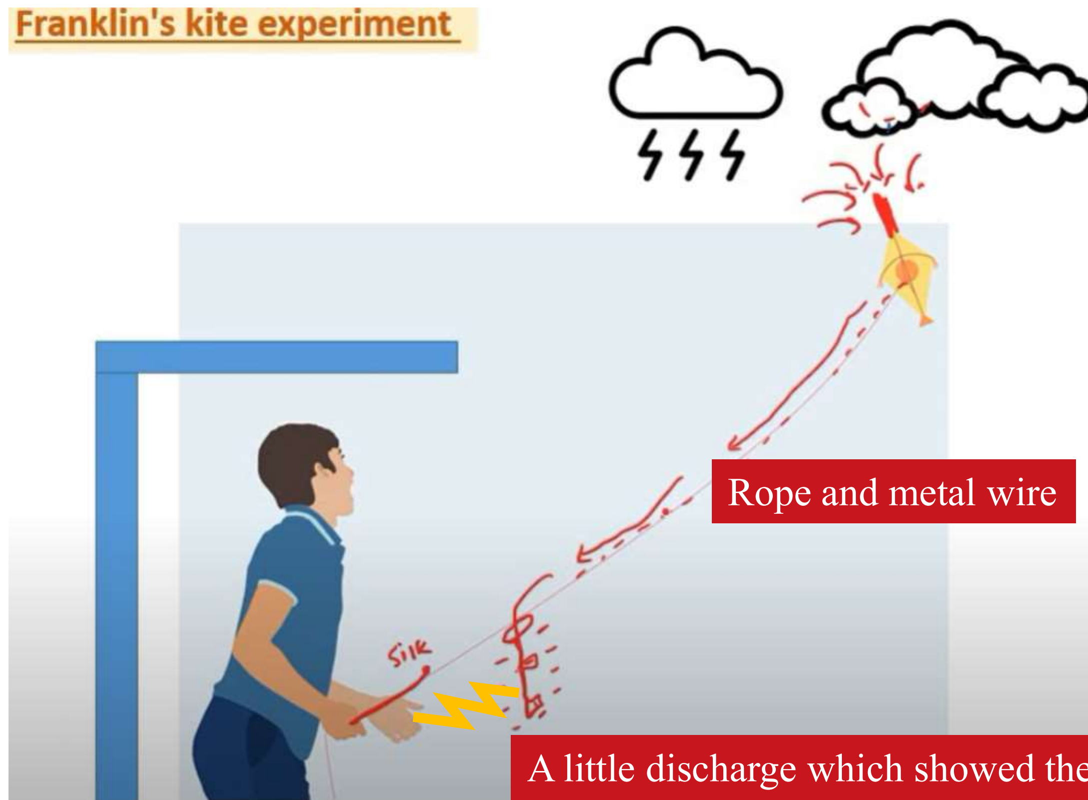
Also pointed out that the earth is a magnetic sphere, by an experiment with small magnetic needles and a magnetized sphere.



Benjamin Franklin

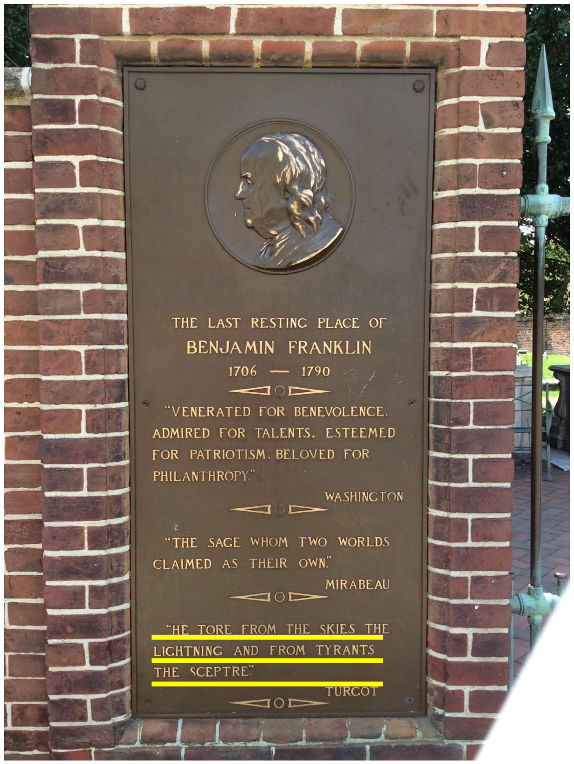
Benjamin Franklin (1706-1790)

https://www.youtube.com/watch?v=SbpA7gATcLo



Rope and metal wire

A little discharge which showed the connection between lightening and electrostatic discharge.



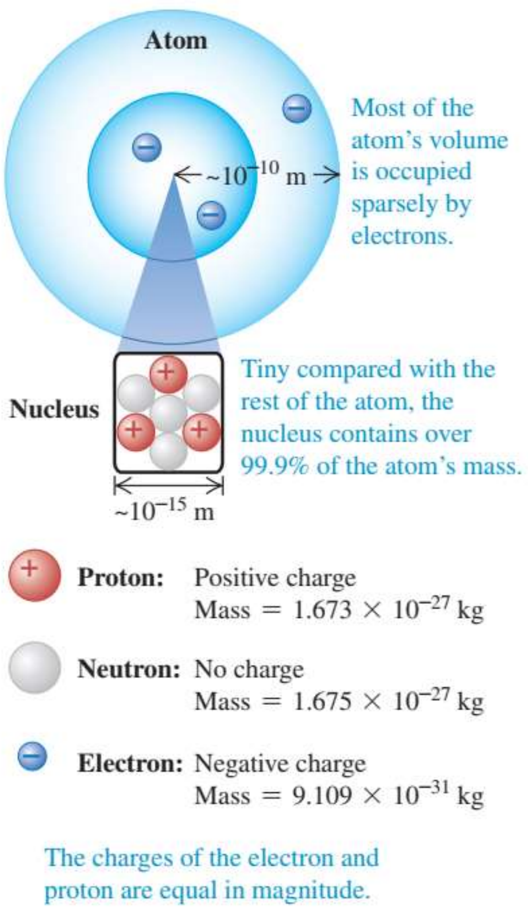
Tyrant: 专制者
Sceptre: 权杖

1. Established the relationship between lightening and electricity;
2. Invented the lightening conductor;
3. Established terms such as conductor, cation, anion, charge, discharge.

Not Everyone is as lucky as Franklin. The first scientist died when studying lightening ia a Russian scientist named Richmann.

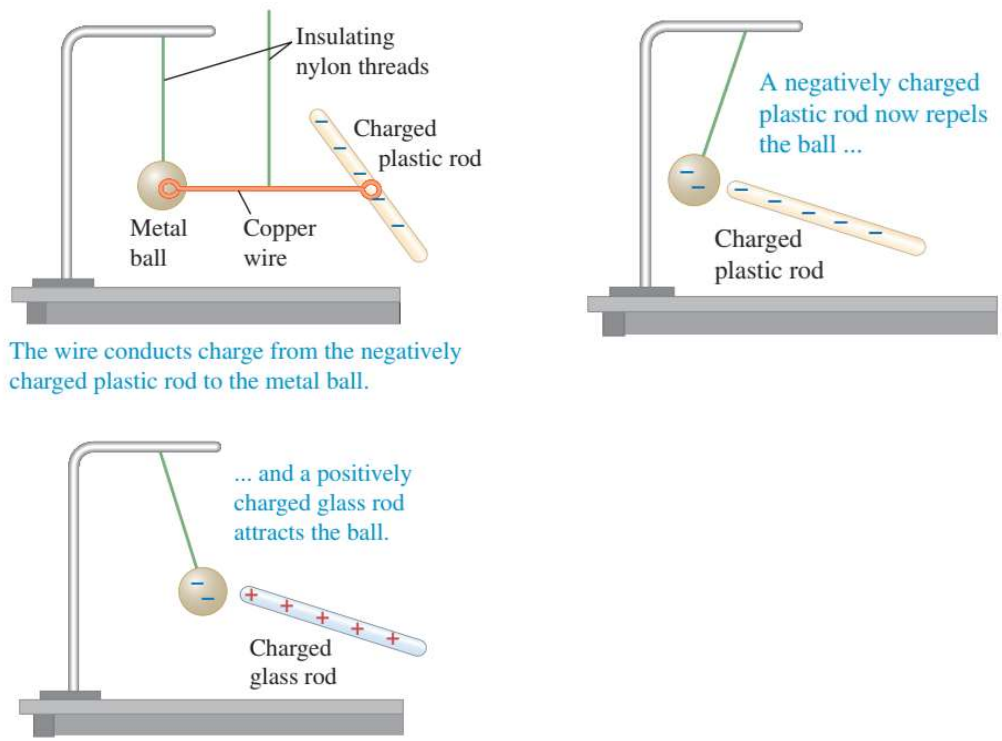
Electrical charge and the structure of matter

21.3 The structure of an atom. The particular atom depicted here is lithium (see Fig. 21.4a).



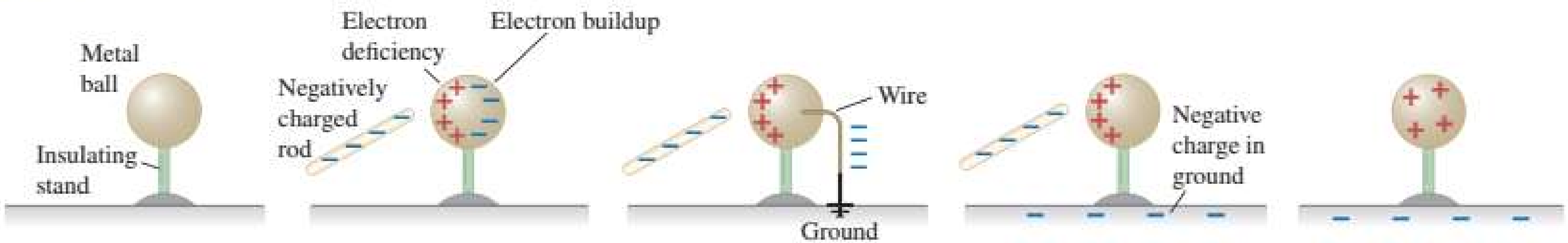
Ways to get material charged:

1. Rub
2. conduction



Another way to get object charged: induced charge in conductors

21.7 Charging a metal ball by induction.



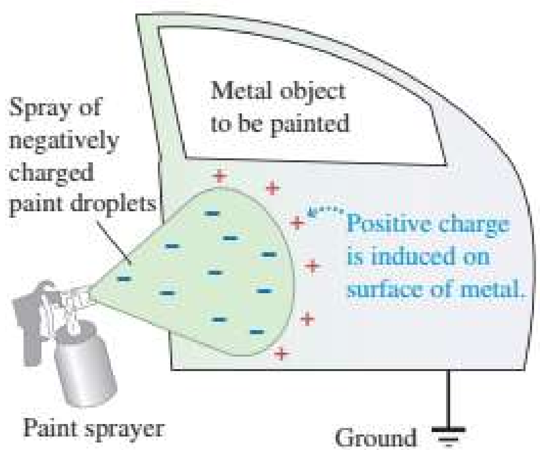
(a) Uncharged metal ball

(b) Negative charge on rod repels electrons, creating zones of negative and positive **induced charge**.

(c) Wire lets electron build-up (induced negative charge) flow into ground.

(d) Wire removed; ball now has only an electron-deficient region of positive charge.

(e) Rod removed; electrons rearrange themselves, ball has overall electron deficiency (net positive charge).



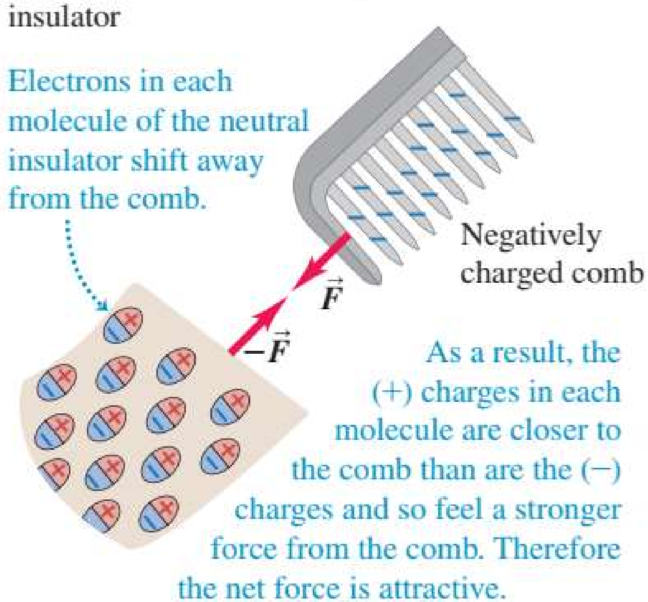
21.9 The electrostatic painting process (compare Figs. 21.7b and 21.7c). A metal object to be painted is connected to the earth ("ground"), and the paint droplets are given an electric charge as they exit the sprayer nozzle. Induced charges of the opposite sign appear in the object as the droplets approach, just as in Fig. 21.7b, and they attract the droplets to the surface. This process minimizes overspray from clouds of stray paint particles and gives a particularly smooth finish.

Induced charge in insulators

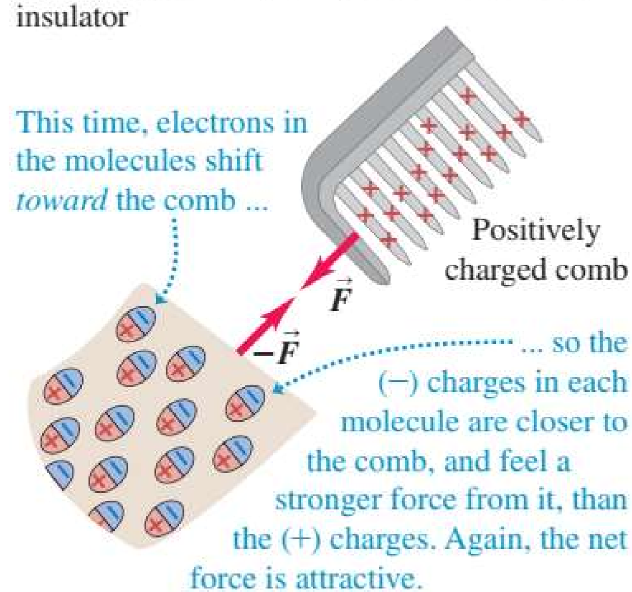
21.8 The charges within the molecules of an insulating material can shift slightly. As a result, a comb with either sign of charge attracts a neutral insulator. By Newton's third law the neutral insulator exerts an equal-magnitude attractive force on the comb.

(a) A charged comb picking up uncharged pieces of plastic

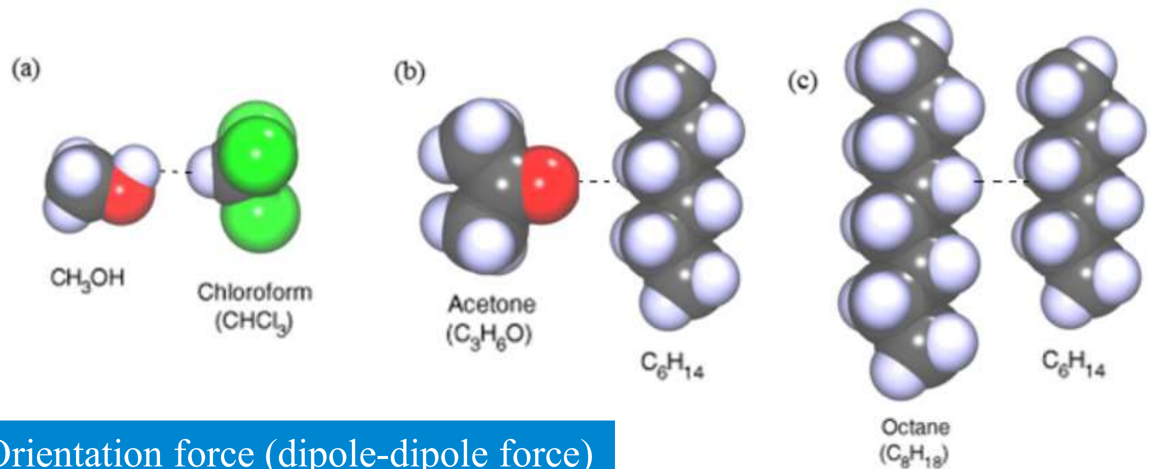
(b) How a negatively charged comb attracts an insulator



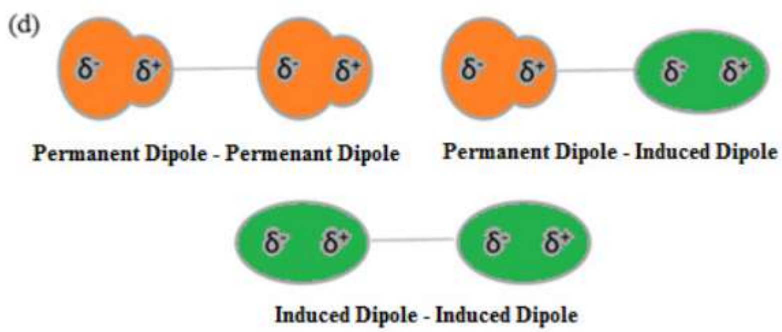
(c) How a positively charged comb attracts an insulator



Microscopic analogy: molecular forces



Orientation force (dipole-dipole force)



Induction force

Dispersion force

Int. J. Mol. Sci. **2012**, *13*, 12773-12856; doi:10.3390/ijms131012773

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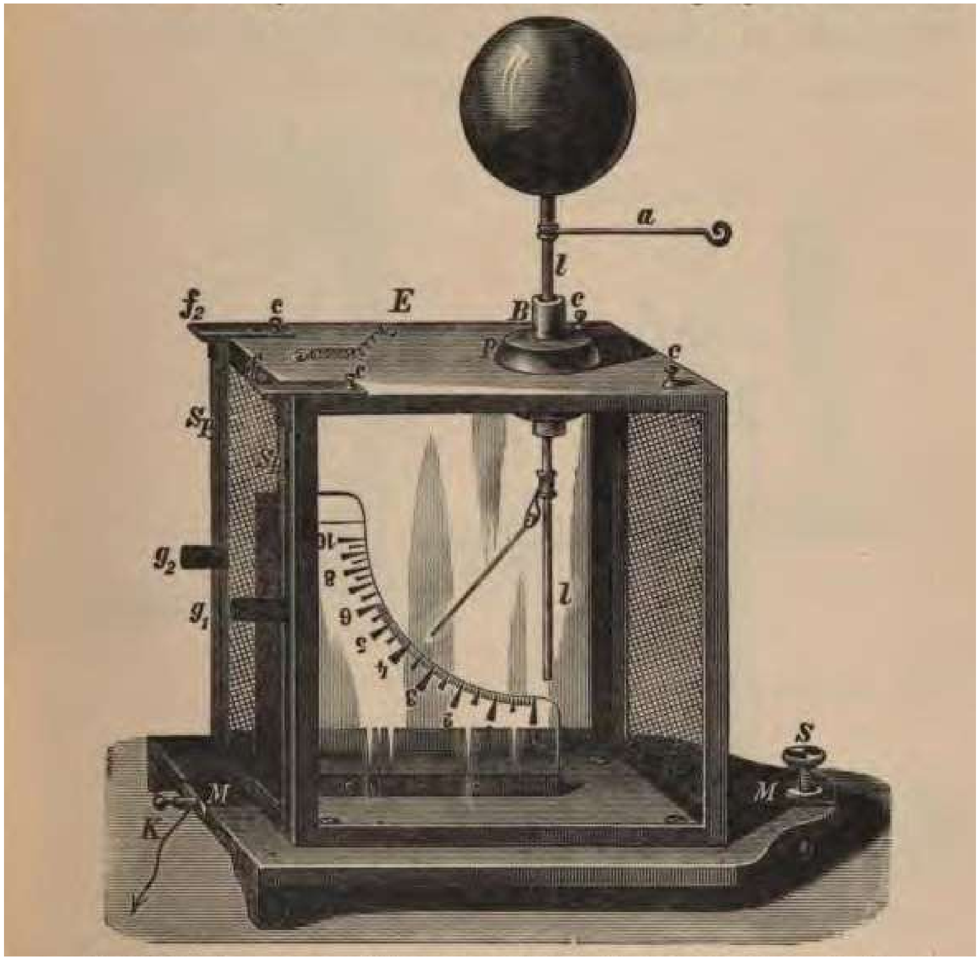
www.mdpi.com/journal/ijms

Review

Theoretical Models for Surface Forces and Adhesion and Their Measurement Using Atomic Force Microscopy

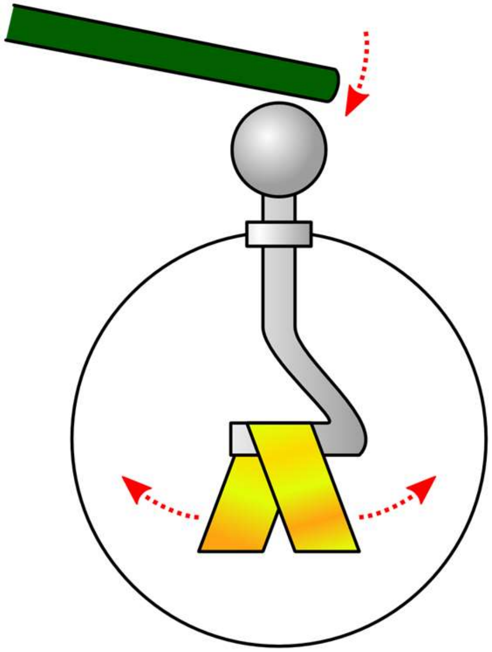
Fabio L. Leite [1,*], Carolina C. Bueno [1], Alessandra L. Da Róz [1], Ervino C. Ziemath [2] and Osvaldo N. Oliveira Jr. [3]

Early instrument to (quantitatively) study electrostatics



https://en.wikipedia.org/wiki/Electrometer

An electrometer, to measure charge (seems the scale is linear to the force, not equally divided).



The more charge the stick carries, the more does the two thin foil separates.

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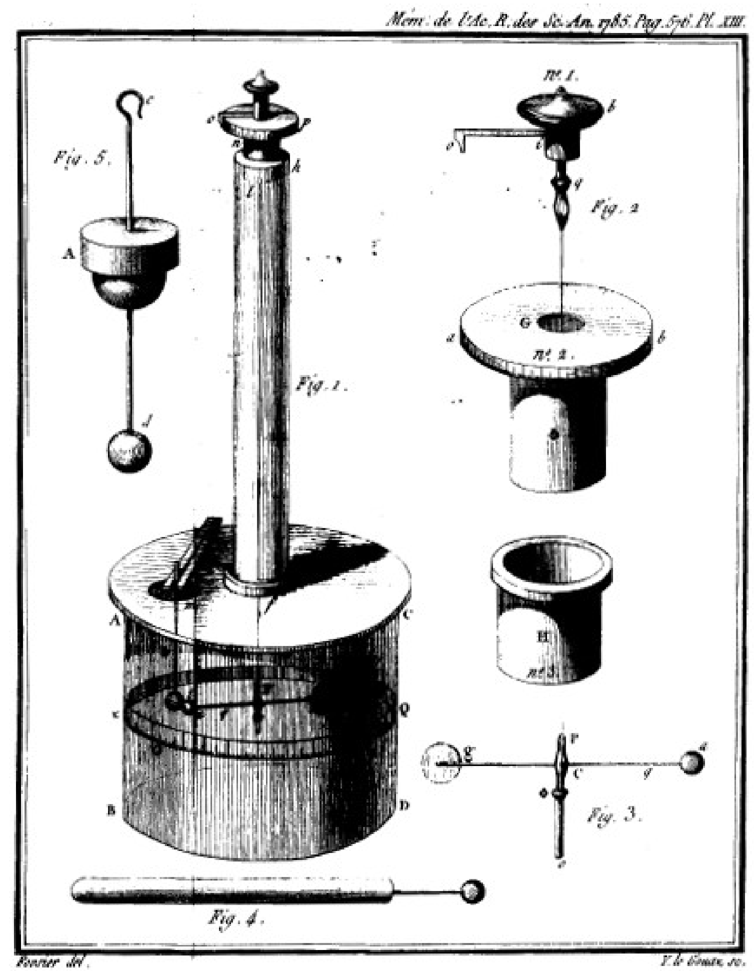
Coulomb’s work

Charles-Augustin de Coulomb
(1736-1806)

French officer, engineer, and physicist

Answered to the rewarded research topic to improve the compass for navigation when he was young, where he used a method similar to the Chinese “缕悬法”

Later, the torsion balance was used for his establishment of Coulomb’s law.



Now assume you are Coulomb, what question do you want to ask?

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If you want to quantitatively describe the interaction (force) between charged objects.

How to measure the force?

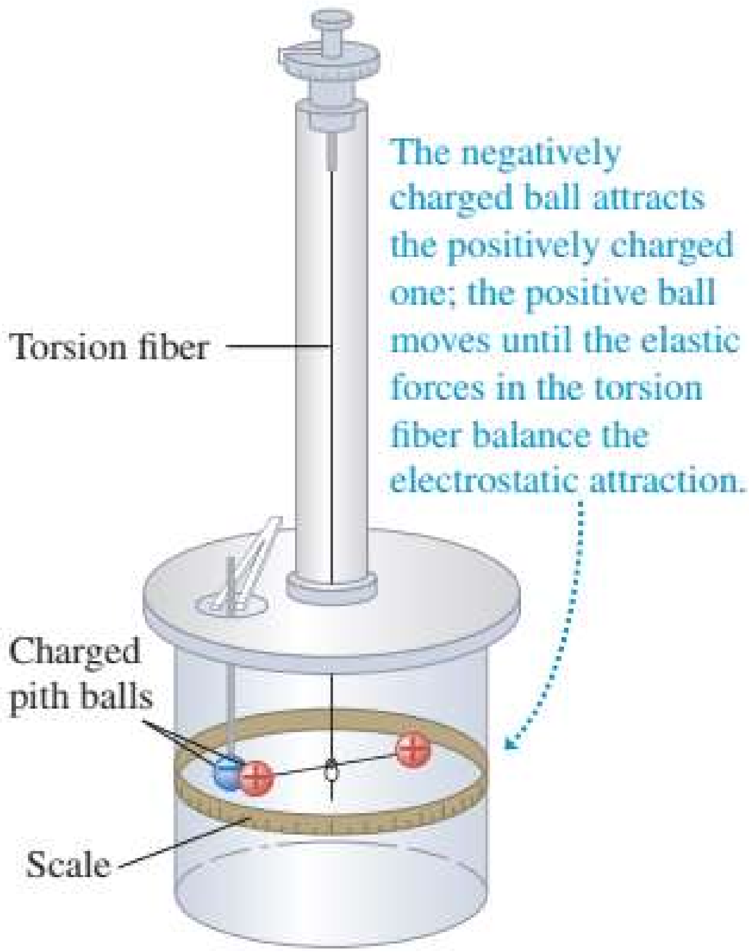
What may influence the force, namely what are x and y for $f = f(x, y)$?

How to quantitatively determine the distance?

What other effects may be involved?

How to quantitatively determine the charge?

Does it really work?



How to measure the force?

Torsion balance

What may influence the force, namely what are x and y for $f = f(x, y)$?

Charge and distance

How to quantitatively determine the distance?

Mark the circumference

What other effects may be involved?

Air flow, balance of the arm, charge bleeding

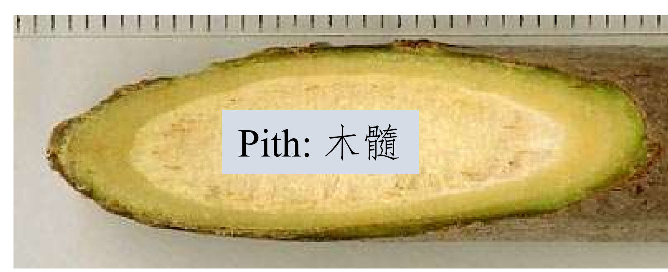
How to quantitatively determine the charge?

Half / half

Does it really work?

A mistake has been made on the photo from the book.
(The sign of the charge, it can only be done for repulsion.)

Then, how to do it for attraction?



Coulomb’s results

For distance,
He found that the torsion rotates when the distance between the two charged sphere is.

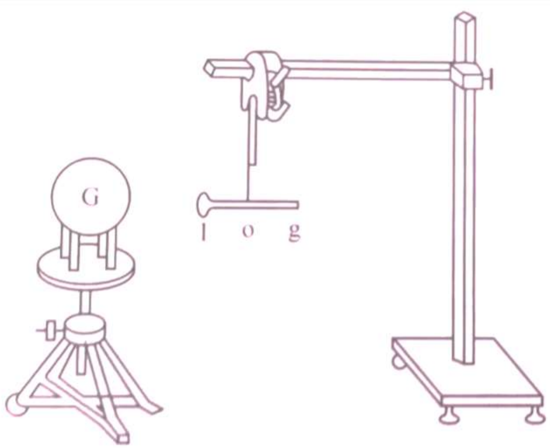
36°	144°	575.5°
36°	18°	8.5°

$$F \propto r^{-2}$$

For effect of charge, he used two identical **conducting** sphere to divide the charge by half and so on, and found

$$F \propto Q_1 Q_2$$

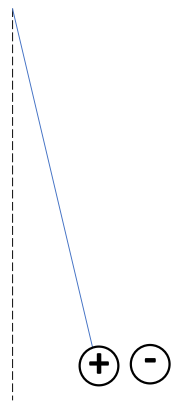
For attraction of opposite charge, he used an electric pendulum for the experiment.



$$T = 2\pi\sqrt{\frac{L}{g}} = 2\pi r\sqrt{\frac{L}{MG}}$$

$$T \propto r$$

My (wrong) imagination



How to write down Coulomb's law in equation?

$$F \propto r^{-2}$$

$$F \propto Q_1 Q_2$$

How about

$$F = \frac{Q_1 Q_2}{r^2}$$

$$\dim\ Q = (\text{force} \cdot \text{distance}^2)^{1/2} = \left(\frac{\text{kg}\cdot\text{m}^3}{\text{s}^2}\right)^{1/2} = \frac{\text{m}}{\text{s}}\sqrt{\text{kg}\cdot\text{m}}$$

In real SI units system, $\dim\ Q = \text{As}$

In SI unit system

$$F = k\frac{|q_1 q_2|}{r^2}$$

$$k = 8.987551787 \times 10^9\ \mathrm{N \cdot m^2/C^2} \cong 8.988 \times 10^9\ \mathrm{N \cdot m^2/C^2}$$

Coulomb's law:

Magnitude of electric force between two point charges

$$F = \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_2|}{r^2} \qquad (21.2)$$

Values of the two charges

Distance between the two charges

Electric constant

$$\epsilon_0 = 8.854 \times 10^{-12}\ \mathrm{C^2/N \cdot m^2} \quad \text{and} \quad \frac{1}{4\pi\epsilon_0} = k = 8.988 \times 10^9\ \mathrm{N \cdot m^2/C^2}$$

Dimension is not unchangeable!

Dimensional analysis (量纲分析) is a very important method to study physics, however, dimension is not invariant. It depends on the unit system.

$$F = \frac{Q_1 Q_2}{r^2}$$

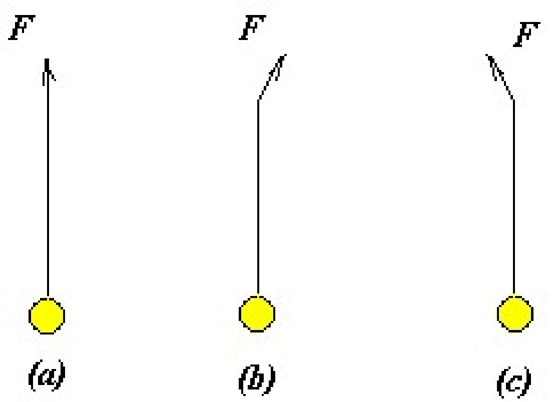
Nothing is wrong with this way of writing. It is actually a real unit system: CGS-ESU (cm-g-s electrostatic units.)

$$\dim Q = (\mathrm{force} \cdot \mathrm{distance}^2)^{1/2} = \left(\frac{\mathrm{g{\cdot}cm^3}}{\mathrm{s}^2}\right)^{1/2} = \frac{\mathrm{cm}}{\mathrm{s}}\sqrt{\mathrm{g \cdot cm}}$$

An independent quantity such as current (Ampere) comes together with a physical constant (ε_0 in this case).

Direction of Coulomb's Force

Can only be along the line connecting the two point charges.



If other component is allowed.

Asymmetric force will be resulted from symmetric rotation.

Coulomb's law

$$\vec{F} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}\hat{r}$$

r, pointing from the source charge to the test charge.

Conservation of charge

The algebraic sum of all the electric charges in any closed system is constant.

Superposition of electric force

Which is the same as saying: the electric force exerted by one charge to another is not affected by a third charge, given that force itself satisfies the vector sum rules.

When is Coulomb’s law valid?

In vacuum

Static

Point charges

Read

Book 21.1 to 21.3