113-2 General Physics II

李傳睿
Chuan-Jui Li

國立政治大學應用物理研究所
Graduate Institute of Applied Physics, NCCU

About me

李傳睿 Chuan-Jui Li (CJLI)

cjli@nccu.edu.tw

https://sites.google.com/view/cjli

Research Area: Observational Astrophysics and Data analysis

(supernovae and their interaction with the interstellar medium)

2004 – 2008 B.S. in Transportation Technology & Management,
National Chiao Tung University

2008 – 2010 M.S. in Physics
National Chiao Tung University

2010 – 2018 Ph.D. in Astrophysics
National Taiwan University

2018 – 2021 ASIAA Postdoctoral Fellow (RDSS)

2022 – 2024 AS Postdoctoral Fellow

2024 NCCU Assistant Professor

This Lecture

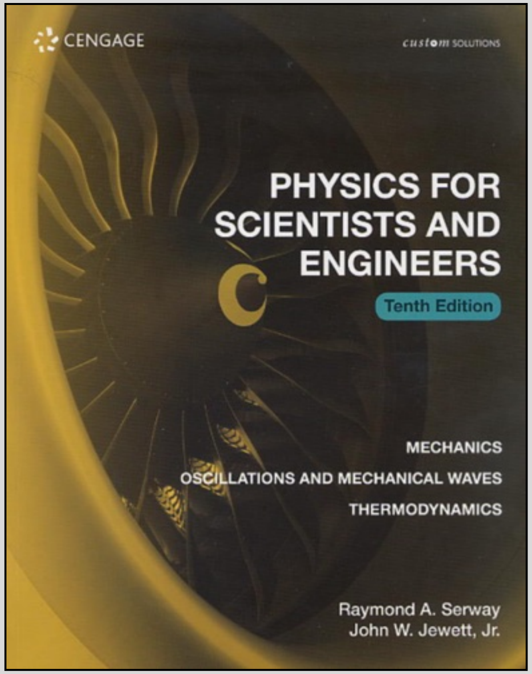
- About Me
  - My Research
- About "General Physics II"
  - Fascinating Electricity & Magnetism

Electric fields

- Electric charges
- Conductors and Insulators
- Coulomb's Law
- Electric fields

References

- **R. A. Serway and J. W. Jewett Jr.,**
  Physics for Scientists and Engineers
  - Part 4 Electricity and Magnetism
  - Part 5 Light and Optics



- R. Feynman, R. Leighton, and M. Sands,
  The Feynman Lectures on Physics
  https://www.feynmanlectures.caltech.edu/

Syllabus

Week 01	(02/17)	Electric fields
Week 02	(02/24)	Gauss's law
Week 03	(03/03)	Electric potential
Week 04	(03/10)	Capacitance and dielectrics
Week 05	(03/17)	Current and resistance
Week 06	(03/24)	Direct current circuits
Week 07	(03/31)	Magnetic fields
Week 08	(04/07)	Faraday's law
Week 09	**(04/14)**	**Midterm**
Week 10	(04/21)	Inductance
Week 11	(04/28)	Alternating current circuits
Week 12	(05/05)	Electromagnetic waves
Week 13	(05/12)	The nature of light and the laws of geometric optics
Week 14	(05/19)	Image formation
Week 15	(05/26)	Interference of light waves
Week 16	**(06/02)**	**Final Exam**
Week 17–18	(06/09, 06/16)	Capstone Self-Learning

Part 4 Electricity and Magnetism

Part 5 Light and Optics

Gradings and Scores

- Homework (30%)
    - Assigned every 1 or 2 weeks (on Moodle)
    - Due 1 week (before the next class, printed or online submission)
        - One-week submission: 100% credit.
        - Afterwards: 70% credit.
- Midterm (30%)
- Final Exam (30%)
- Class participation (10%)

Office Hours

- 教師：李傳睿 Chuan-Jui Li (CJLI)

  cjli@nccu.edu.tw

  https://sites.google.com/view/cjli

- 助教: 楊斯皓

  113-2 哲學系大四 (雙主修電物)

  114-1 應物所

  110104035@nccu.edu.tw

- 請寄信: 1. 查閱郵件禮儀 2. 註明系級姓名
  3. 簡述問題 4. 預約時間

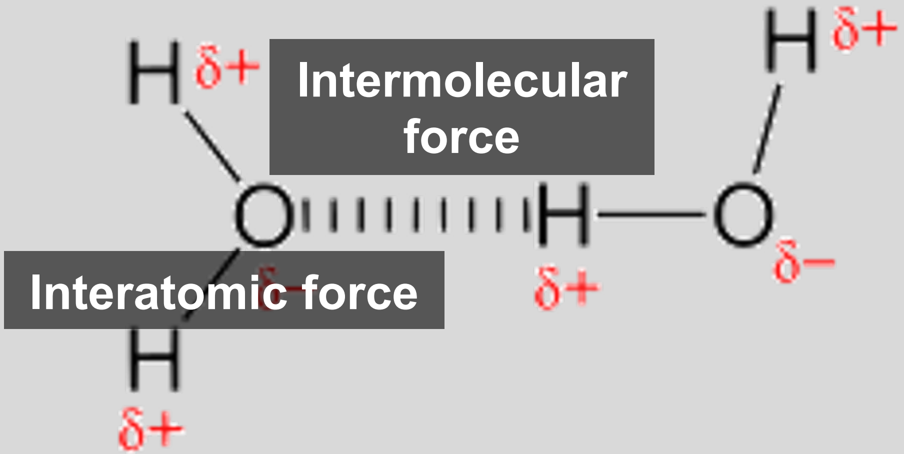
- 一起維持鼓勵學習的環境。

  如果同學比較內向，歡迎寄信表達，合理都會聆聽。

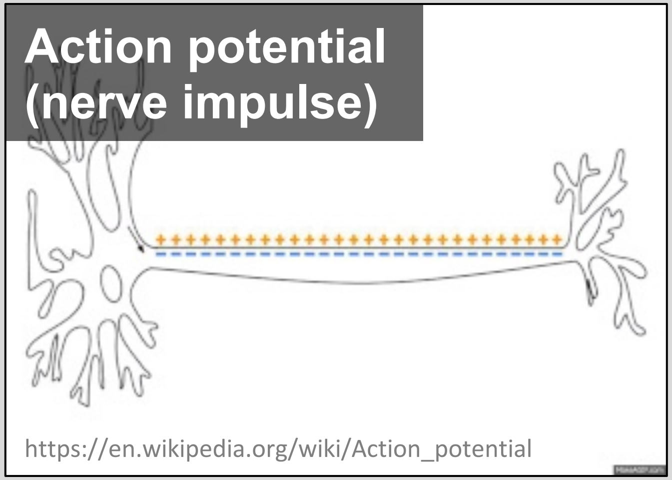
- 信用比分數珍貴，請說真話。

Fascinating Electricity & Magnetism

Hydrogen bonding in water

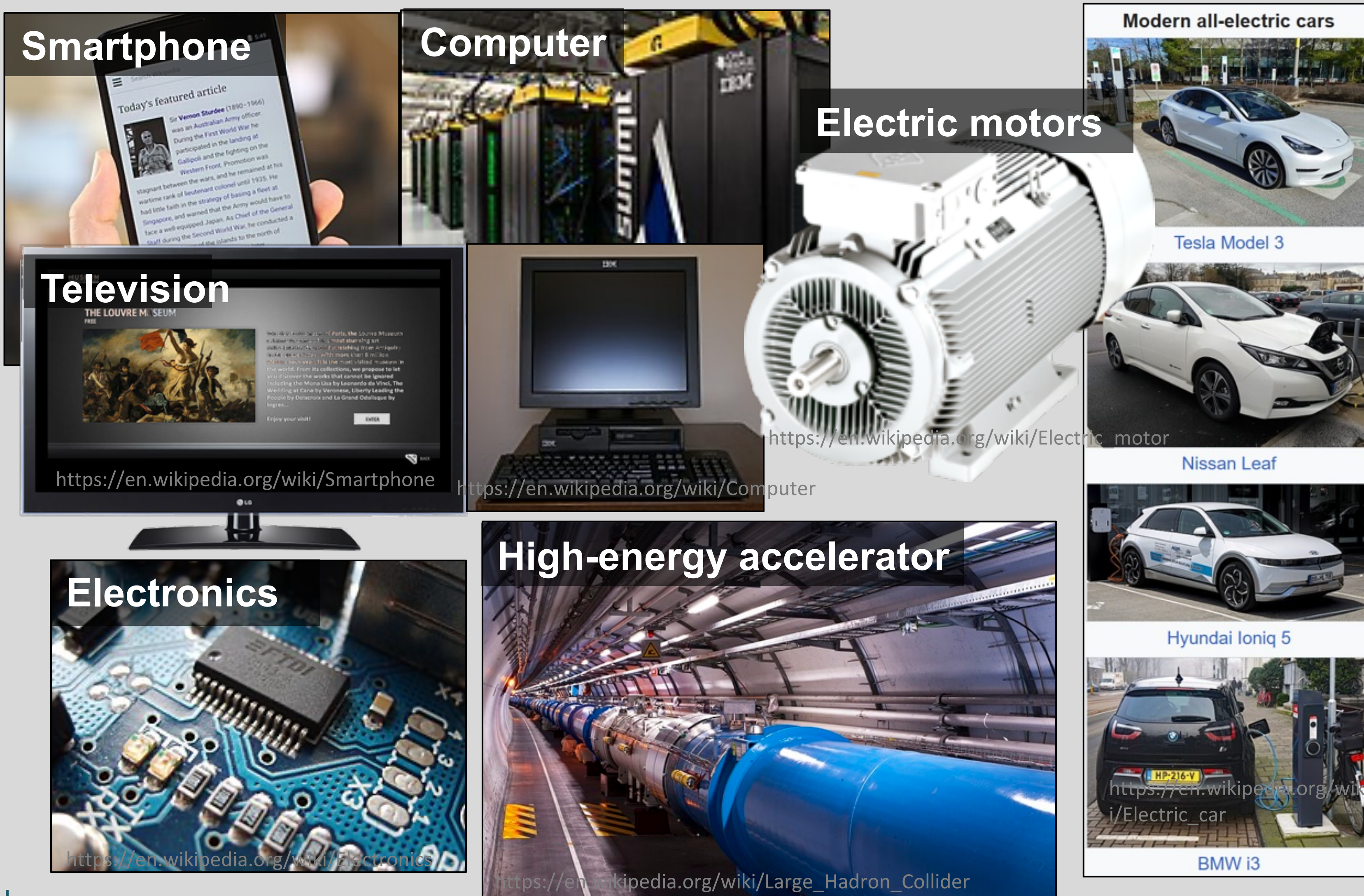


https://en.wikipedia.org/wiki/Intermolecular_force



Fascinating Electricity & Magnetism

Any sufficiently advanced technology is indistinguishable from magic – C. Clarke



Fascinating Electricity & Magnetism

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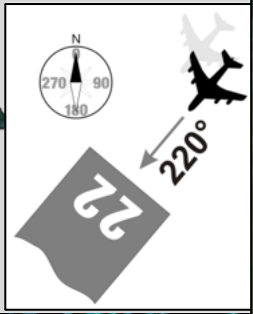
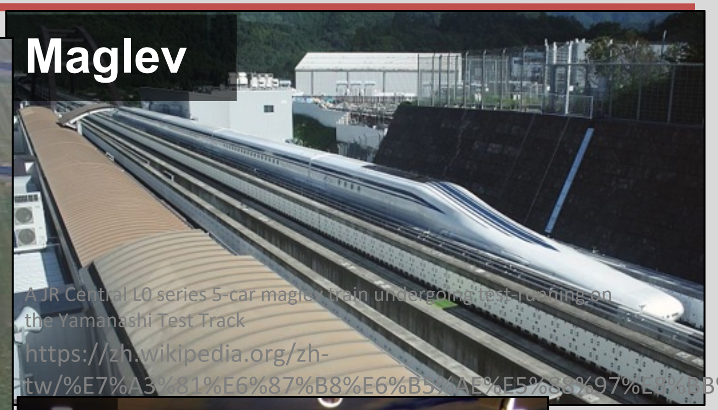
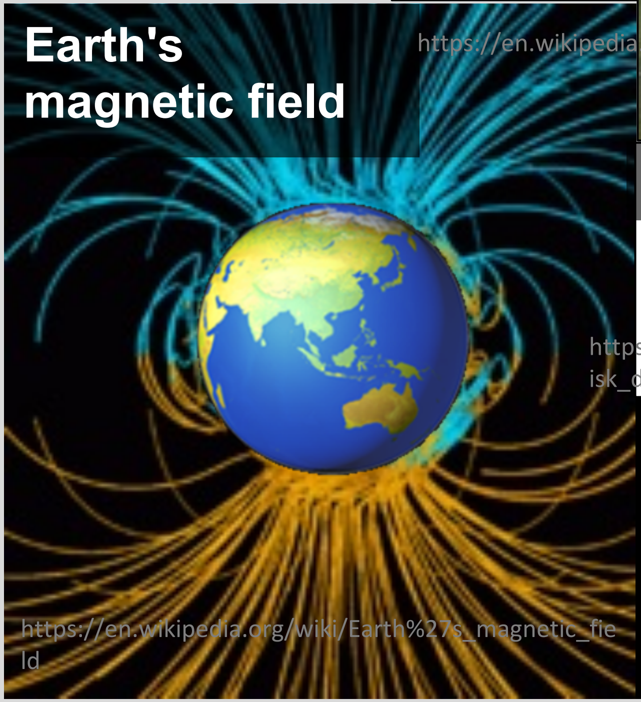
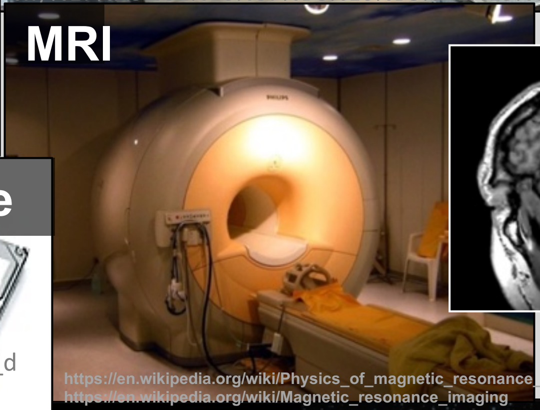
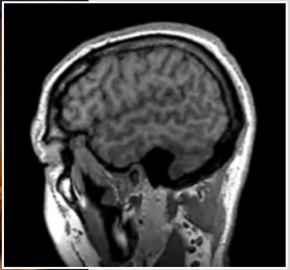
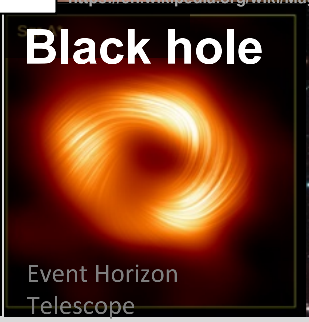




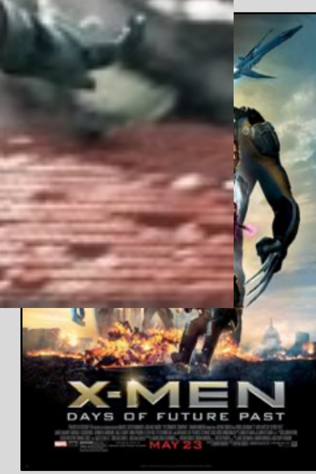








Fascinating Electricity & Magnetism

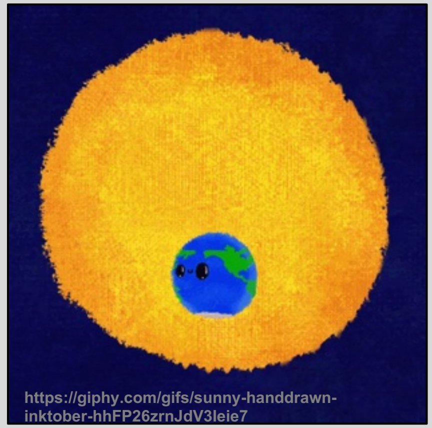


X-Men Magneto萬磁王

https://en.wikipedia.org/wiki/X-Men:_Days_of_Future_Past
https://www.youtube.com/watch?v=pAApe_5Rewg

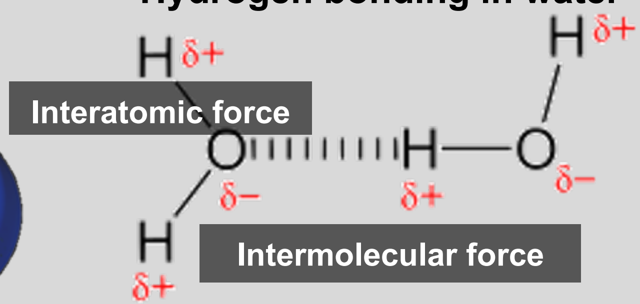
Fascinating Electricity & Magnetism

Gravity



Electric forces

Hydrogen bonding in water



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

Biology

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

Chemistry

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

This Lecture

- About Me
  - My Research
- About “General Physics II”
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Electric fields

- Electric charges
- Conductors and Insulators
- Coulomb’s Law
- Electric fields

Lecture 01 – chapter 23
Electric Fields

蔡尚岳
政治大學應用物理所

Lecture 01 – chapter 23
Electric Fields

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政治大學應用物理所

為了保留蔡老師的原創，以及不影響同學閱讀，
若左下角標註 CJLI，代表內容已作更動或新增。

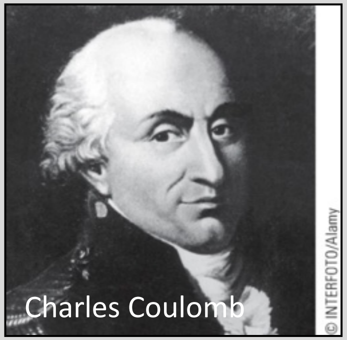
CJLI

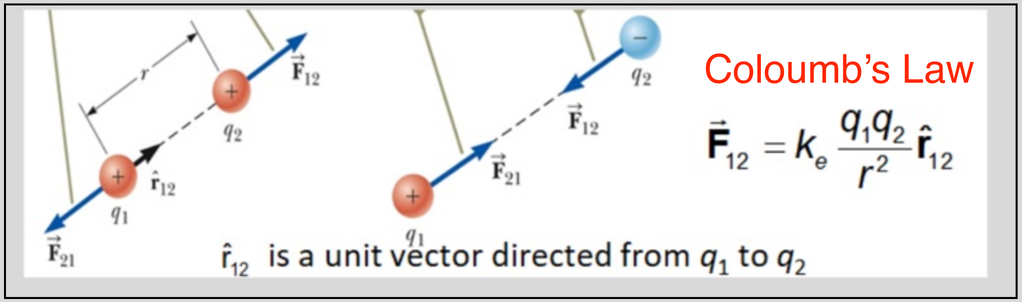
Some History

Not until the early 19th century did scientists establish electricity and magnetism as related phenomena.

- 1785
  - Charles Coulomb confirmed inverse square law form for electric forces

In the upcoming slides





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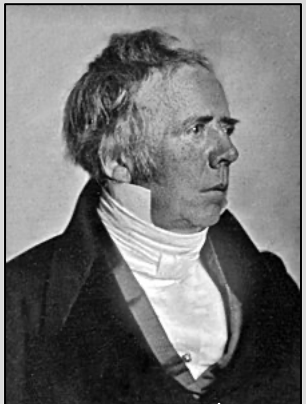
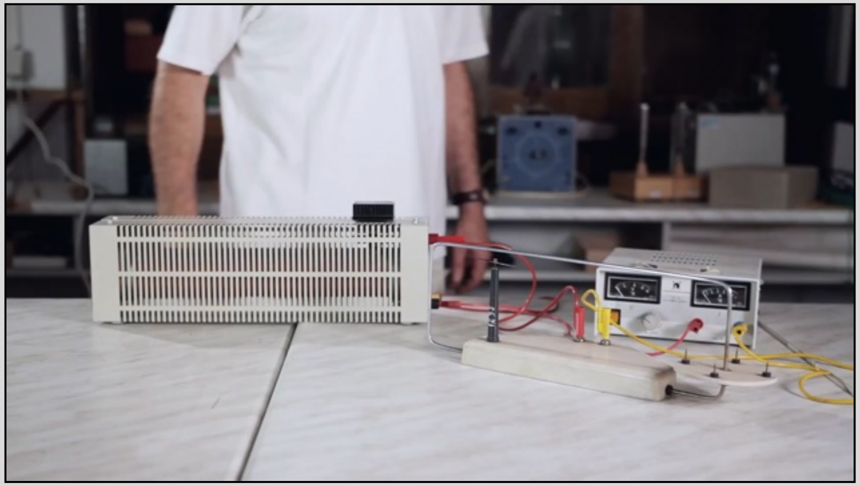

Hans Christian Ørsted



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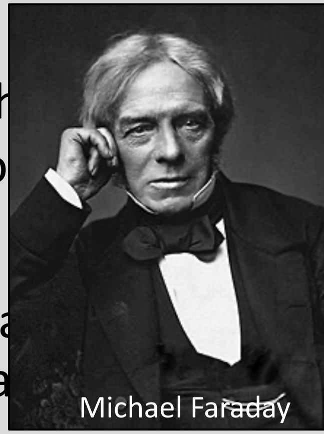
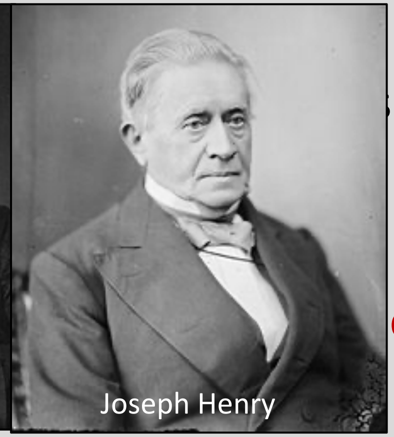
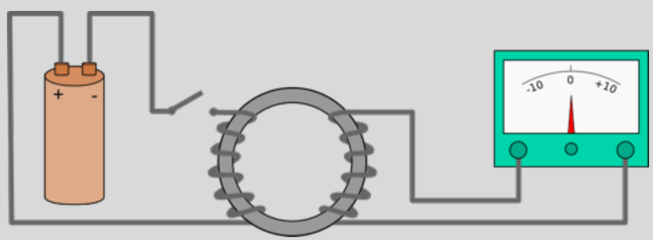




- 1831
  - Michael Faraday and Joseph Henry showed that when a **wire is moved near a magnet**, an electric current is produced in the wire

Faraday's 1831 demonstration



A change in the magnetic flux of the left coil induces a current in the right coil.

Later this semester

https://en.wikipedia.org/wiki/Joseph_Henry
https://en.wikipedia.org/wiki/Michael_Faraday
https://en.wikipedia.org/wiki/Faraday%27s_law_of_induction

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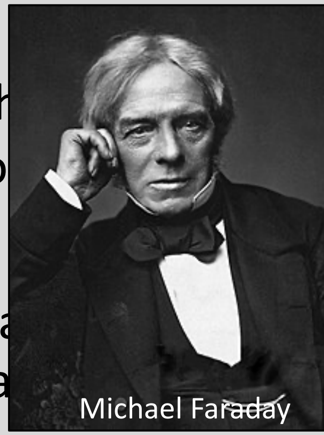

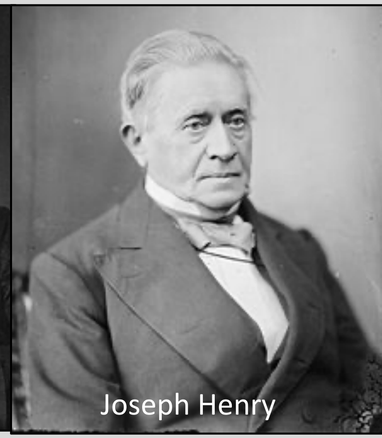

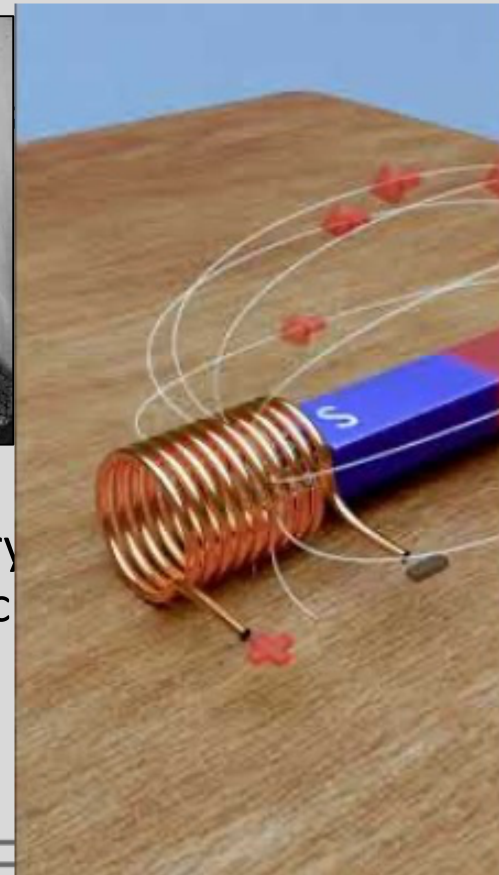

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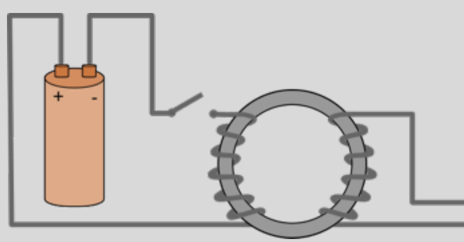

…magnetic …l induces …ght coil.

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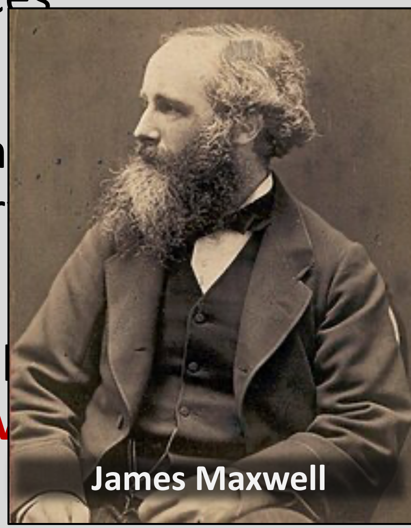
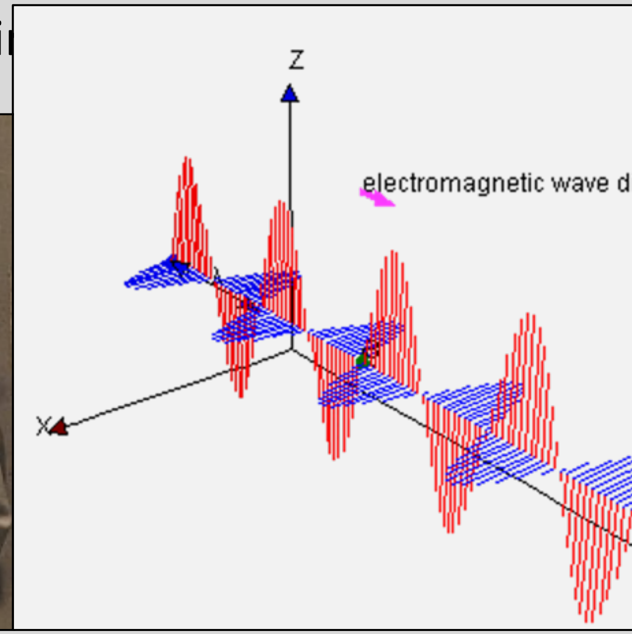
  - Unified electricity and magnetism





https://en.wikipedia.org/wiki/Electromagnetic_radiation
https://en.wikipedia.org/wiki/James_Clerk_Maxwell

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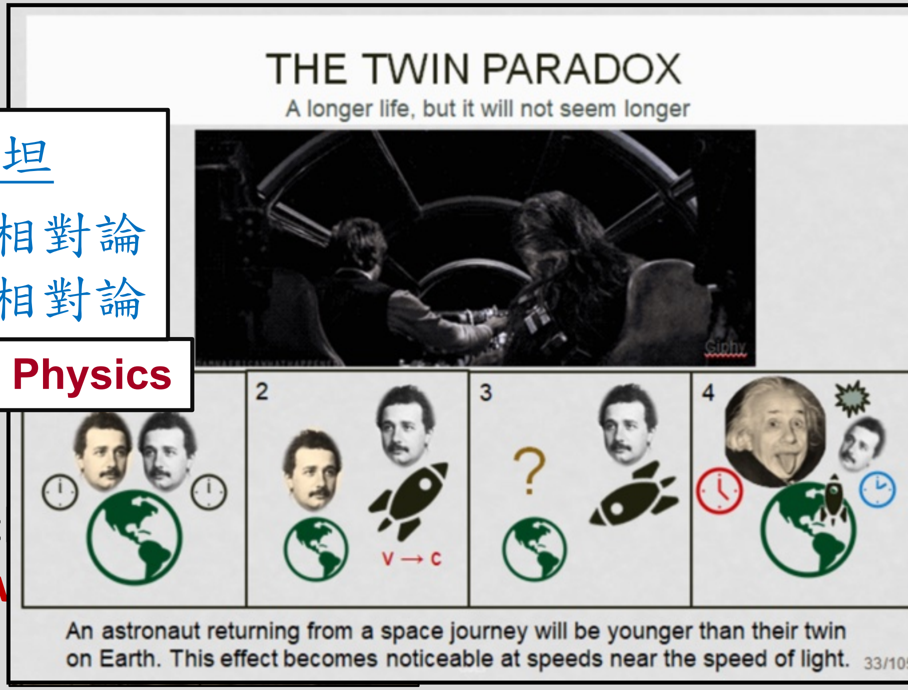
愛因斯坦

1905 狹義相對論
1915 廣義相對論

114-1 Modern Physics



Movie *Interstellar* 2014

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    mov
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Electric Charges (電荷)

- Two kinds of electric charges
  - **Negative charges** : electrons
  - **Positive charges** : protons
  - Repel (same sign) or Attract (opposite signs)

charge conservation

- Electric charge is **conserved** in an isolated system
  - **Electrification** : **transfer of charge** from one object to another
  - Example : A glass rod is rubbed with silk
    - Electrons are transferred from the glass to the silk

Quantization of Electric Charges

- The electric charge, q, is said to be **quantized**
  - $q = \pm Ne$ (Robert A. Millikan)
    - N is an integer
    - e is the fundamental unit of charge, $|e| = 1.6 \times 10^{-19}$ C
    - The SI unit of charge is the **coulomb (C)**

elementary charge e = 1.602176634×10^-19 coulombs (SI unit)

Table 23.1 Charge and Mass of the Electron, Proton, and Neutron

Particle	Charge (C)		Mass (kg)
Electron (e)	$-1.602\,176\,5 \times 10^{-19}$	(-e)	$9.109\,4 \times 10^{-31}$
Proton (p)	$+1.602\,176\,5 \times 10^{-19}$	(+e)	$1.672\,62 \times 10^{-27}$
Neutron (n)	0		$1.674\,93 \times 10^{-27}$

Quick Quiz 22.1

- Three objects are brought close to each other, two at a time. When objects A and B are brought together, they repel. When objects B and C are brought together, they also repel. Which of the following are true? (Multiple choices)

(a) Objects A and C possess charges of the same sign.

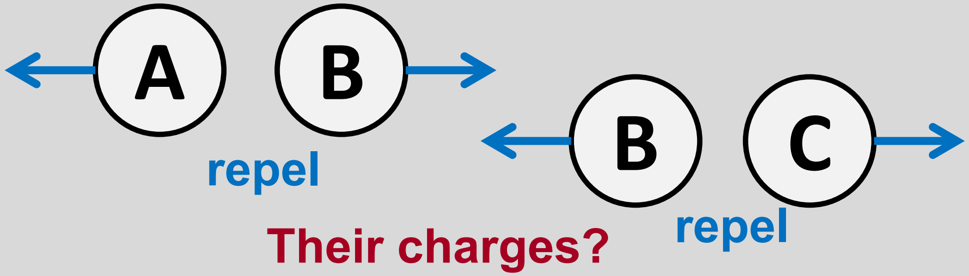
(b) Objects A and C possess charges of opposite sign.

(c) All three objects possess charges of the same sign.

(d) One object is neutral

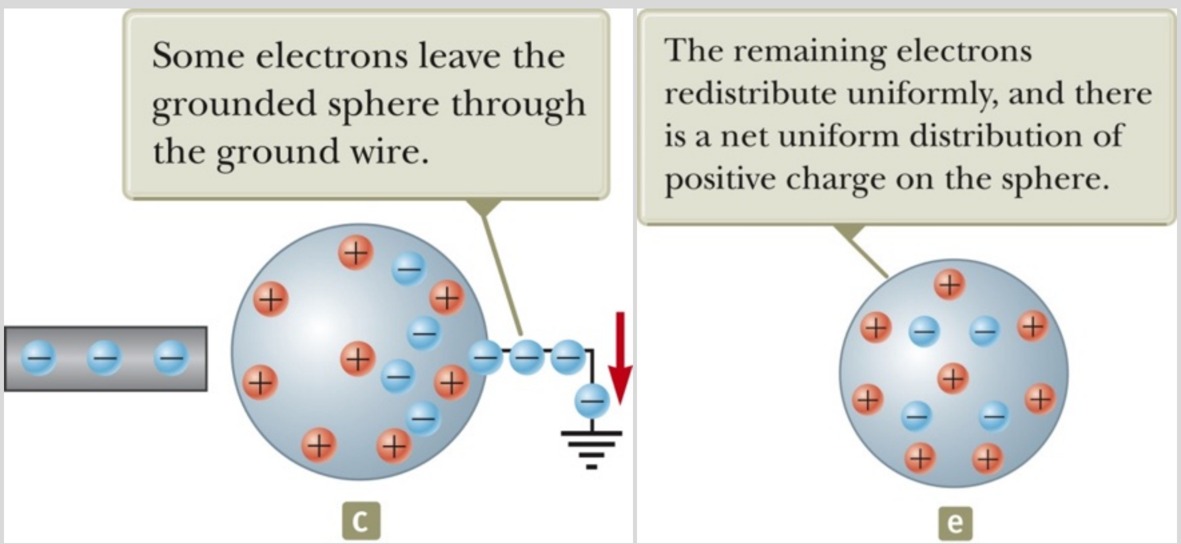
(e) Additional experiments must be performed to determine the signs of the charges.

Answer: (a)(c)(e)

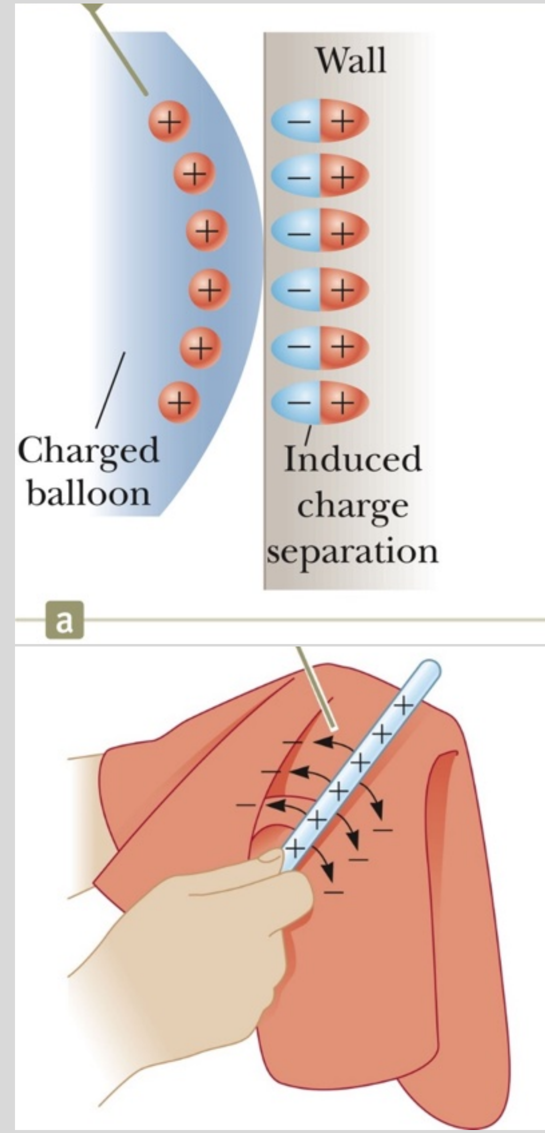


Conductors and Insulators

- Electrical conductors (導體)
  - **Some** of the electrons are **free electrons**
  - Move relatively **freely** through the material
- Electrical insulators (絕緣體)
  - **All** of the electrons are **bound to atoms**
- Semiconductors (半導體)



Section 23.2

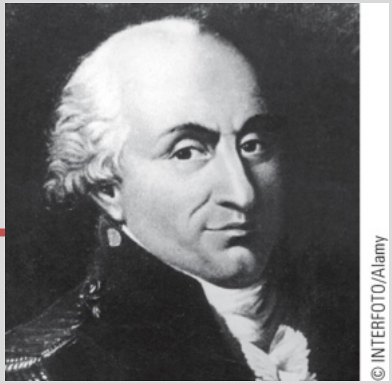


9 Awesome Science Tricks Using Static Electricity!

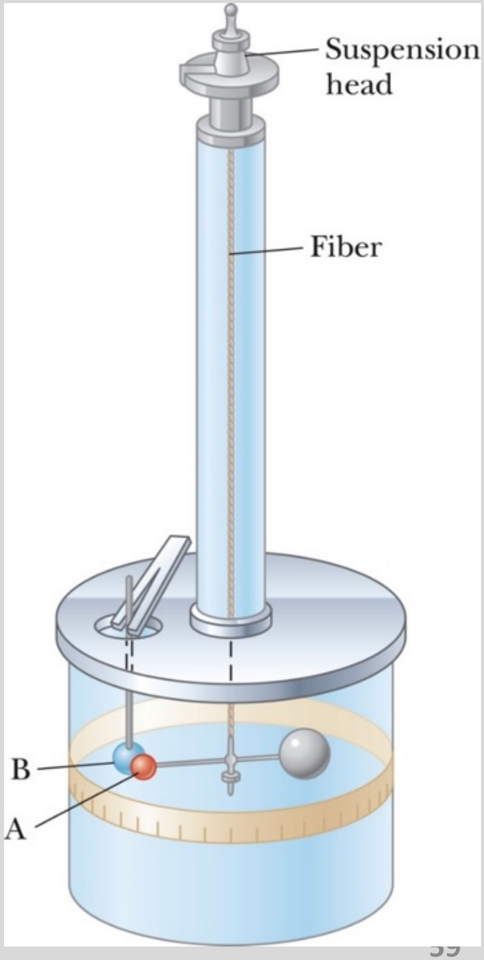
Experiments demonstrate the existence of the electric force.

https://www.youtube.com/watch?v=ViZNgU-Yt-Y

Charles Coulomb



- 1736 – 1806
- French physicist
- Major contributions were in areas of electrostatics and magnetism
- Also investigated in areas of
  – Strengths of materials、Structural mechanics
- Twist angle → Torque → The force between particles
- Same apparatus used by Cavendish to measure the density of Earth



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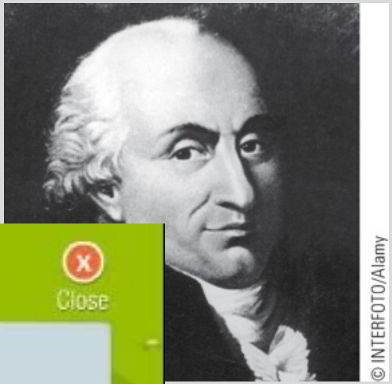

- 1736
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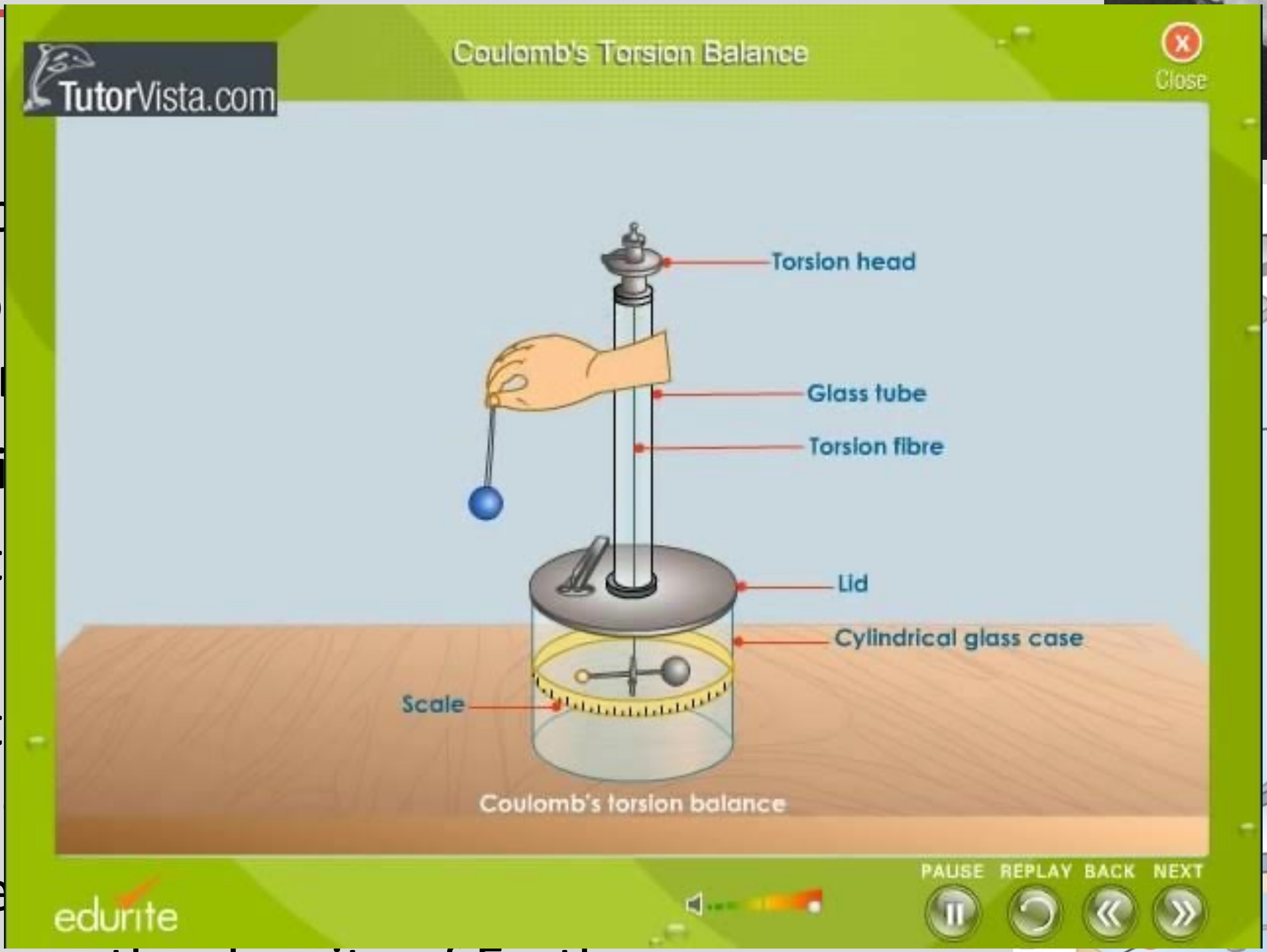
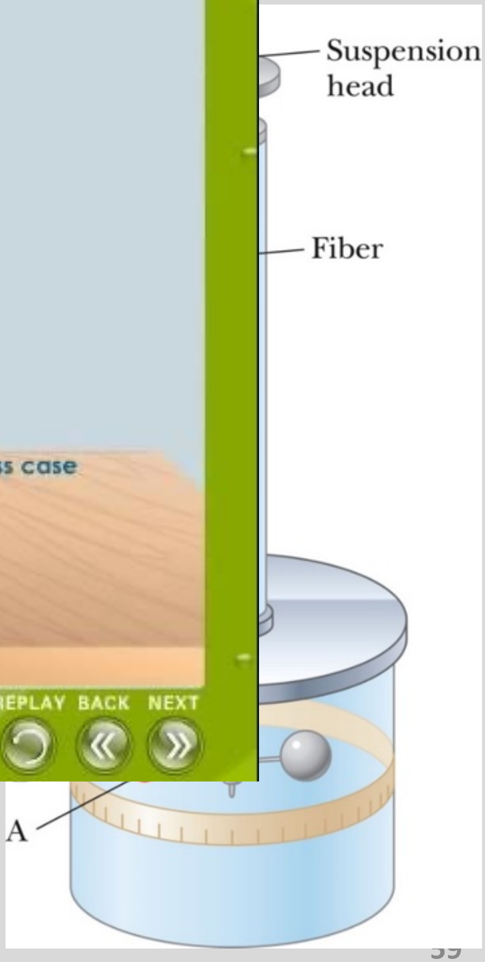




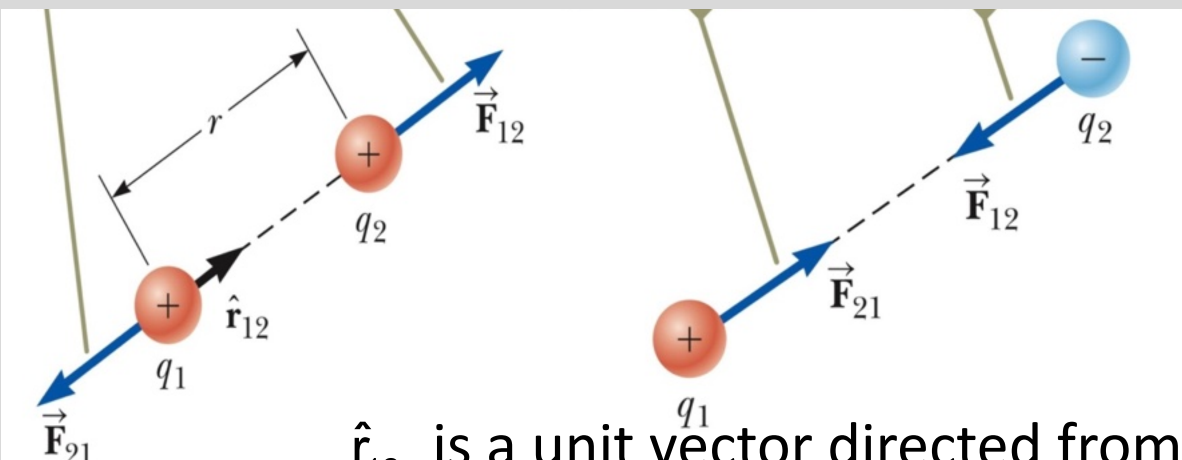
Coulomb's Law（庫倫定律)

$$F_e = k_e \frac{|q_1||q_2|}{r^2}$$

$k = \dfrac{1}{4\pi\varepsilon_0}$

- **Coulomb constant,** k_e = 8.9876 x 10^9 N·m^2/C^2 = **$1/(4\pi\varepsilon_0)$**
- **Permittivity (介電常數) of free space,** ε_0 = 8.8542 x 10^{-12} C^2 / N·m^2

• The force is a **conservative force (保守力)**



$$\vec{F}_{12} = k_e \frac{q_1 q_2}{r^2}\hat{\mathbf{r}}_{12}$$

$\hat{r}_{12}$ is a unit vector directed from q_1 to q_2

In physics, a **conservative force** is a force with the property that the total work done by the force in moving a particle between two points is independent of the path taken.[1] Equivalently, if a particle travels in a closed loop, the total work done (the sum of the force acting along the path multiplied by the displacement) by a conservative force is zero.[2]

A conservative force depends only on the position of the object. If a force is conservative, it is possible to assign a numerical value for the potential at any point and conversely, when an object moves from one location to another, the force changes the potential energy of the object by an amount that does not depend on the path taken, contributing to the mechanical energy and the overall conservation of energy. If the force is not conservative, then defining a scalar potential is not possible, because taking different paths would lead to conflicting potential differences between the start and end points.

Gravitational force is an example of a conservative force, while frictional force is an example of a non-conservative force.

Part of a series on

Classical mechanics

$$\mathbf{F} = \frac{d\mathbf{p}}{dt}$$

Second law of motion

History · **Timeline** · **Textbooks**

Branches [show]

Fundamentals [show]

Formulations [show]

Core topics [show]

Rotation [show]

Scientists [show]

Physics portal **Category**

V · T · E

Other examples of conservative forces are: force in elastic spring, electrostatic force between two electric charges, and magnetic force between two magnetic poles. The last two forces are called central forces as they act along the line joining the centres of two charged/magnetized bodies. A central force is conservative if and only if it is spherically symmetric.[3]

For conservative forces,

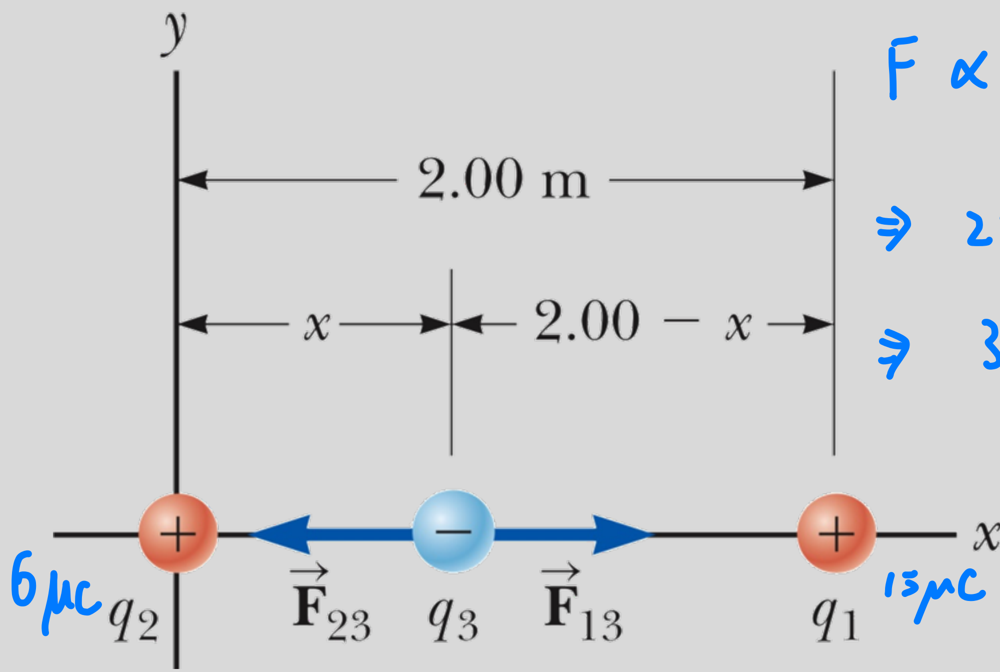
$$\mathbf{F_c} = -\frac{dU}{d\mathbf{s}}$$

where F_c is the conservative force, U is the potential energy, and s is the position.[4]

Multiple Charges

- The vector sum of the forces $\vec{\mathbf{F}}_1 = \vec{\mathbf{F}}_{21} + \vec{\mathbf{F}}_{31} + \vec{\mathbf{F}}_{41}$

- Example 23.3 : q_1 = 15.0 μC , q_2 = 6.00 μC, and the net force acting on q_3 is zero. What is the x coordinate of q_3? **0.775**



$F \propto \frac{q}{r^2} \Rightarrow \frac{\cancel{6}\,2}{x^2} = \frac{\cancel{15}\,5}{(2-x)^2}$

$\Rightarrow 2x^2 - 8x + 8 = 5x^2$

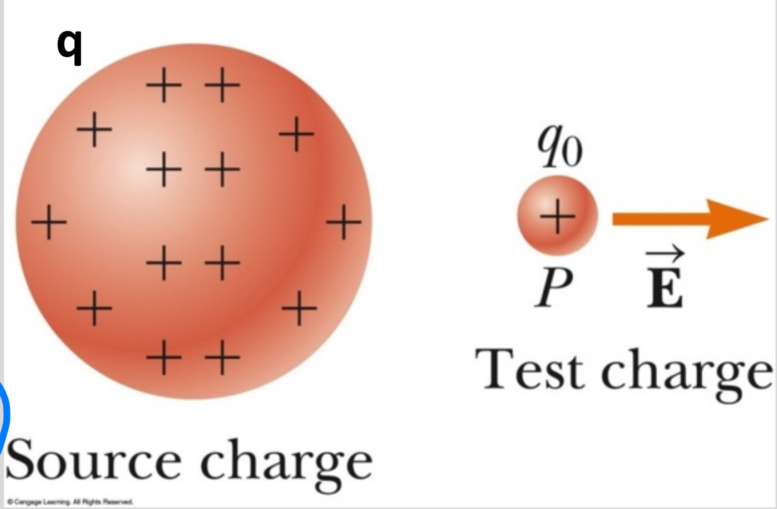
$\Rightarrow 3x^2 + 8x - 8 = 0$

$\Rightarrow x \approx 0.775$

Electric Field (電場)

- **Electric field** exist in the region of space around **a source charge**

- The electric field vector, $\vec{\mathbf{E}}$, is defined as the electric force on the test charge per unit charge (Newton/coulomb)



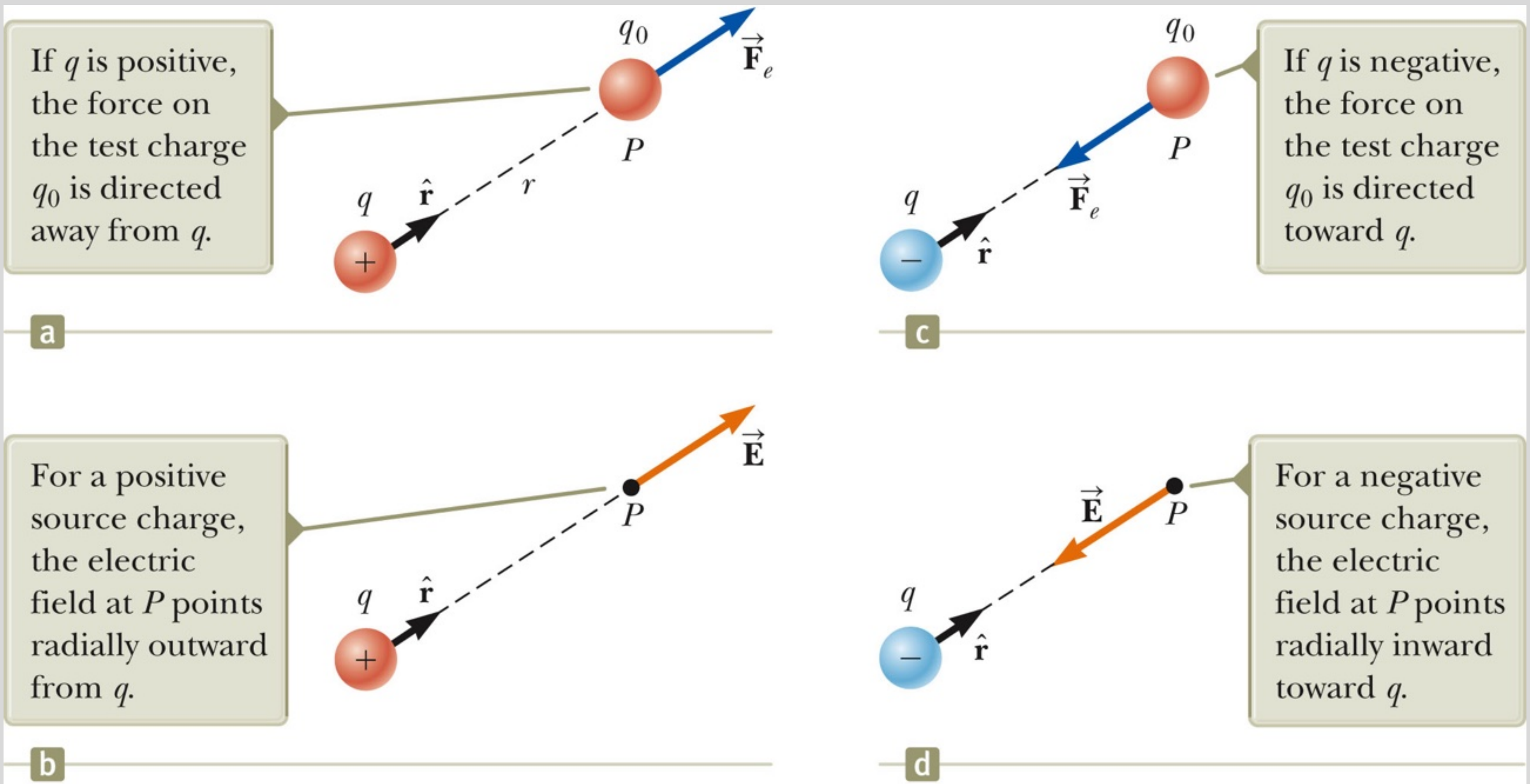
$$\vec{\mathbf{E}} = \frac{\vec{\mathbf{F}}_e}{q_o} = k_e \frac{q}{r^2}\hat{\mathbf{r}}$$

test charge

$$\vec{\mathbf{E}} = k_e \sum_i \frac{q_i}{r_i^2}\hat{\mathbf{r}}_i$$

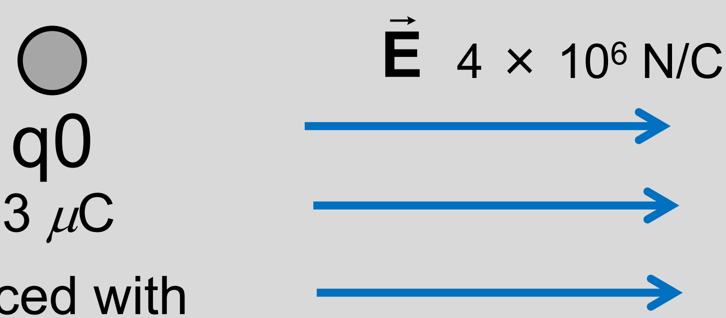
Section 23.4

More About Electric Field Direction



Quick Quiz 23.4

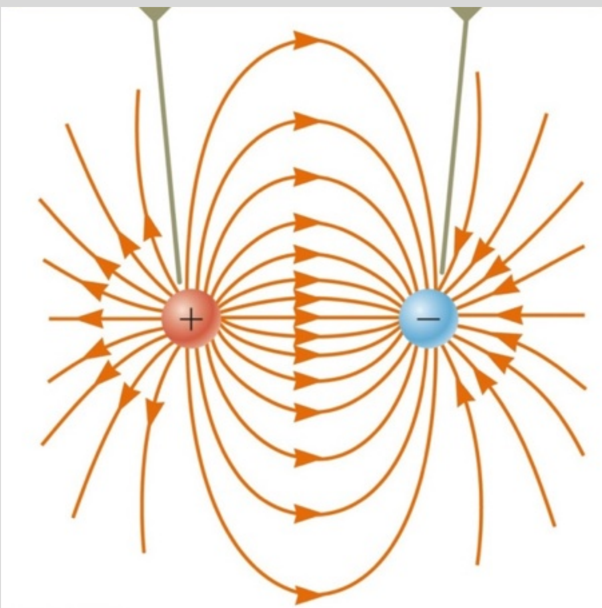
- A test charge of +3 μC is at a point *P* where an external electric field is directed to the right and has a magnitude of 4×10^6 N/C. If the test charge is replaced with another test charge of –3 μC, what happens to the external electric field at *P*?
- (a) It is unaffected.
- (b) It reverses direction.
- (c) It changes in a way that cannot be determined.
- **Answer: (a)**



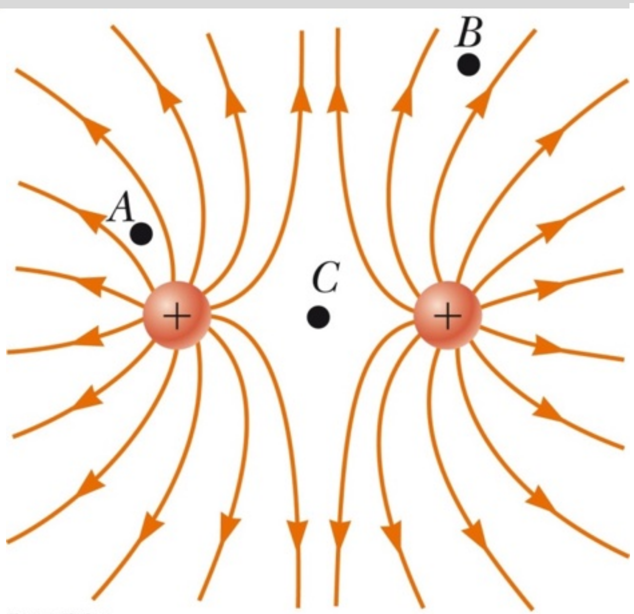
Replaced with
-3 μC, what about E?

Electric Field Lines

- A pictorial representation of electric field
  - “+” → “-”
  - No cross
  - (Number of lines per unit area through a surface) $\propto$ **E**

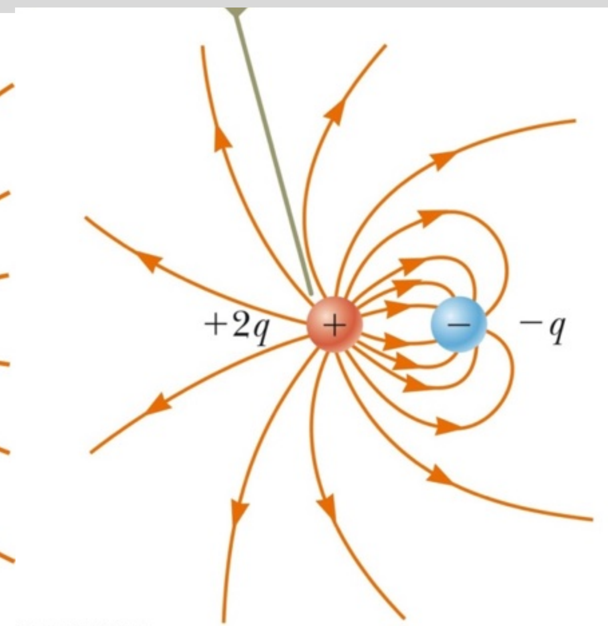


Dipole



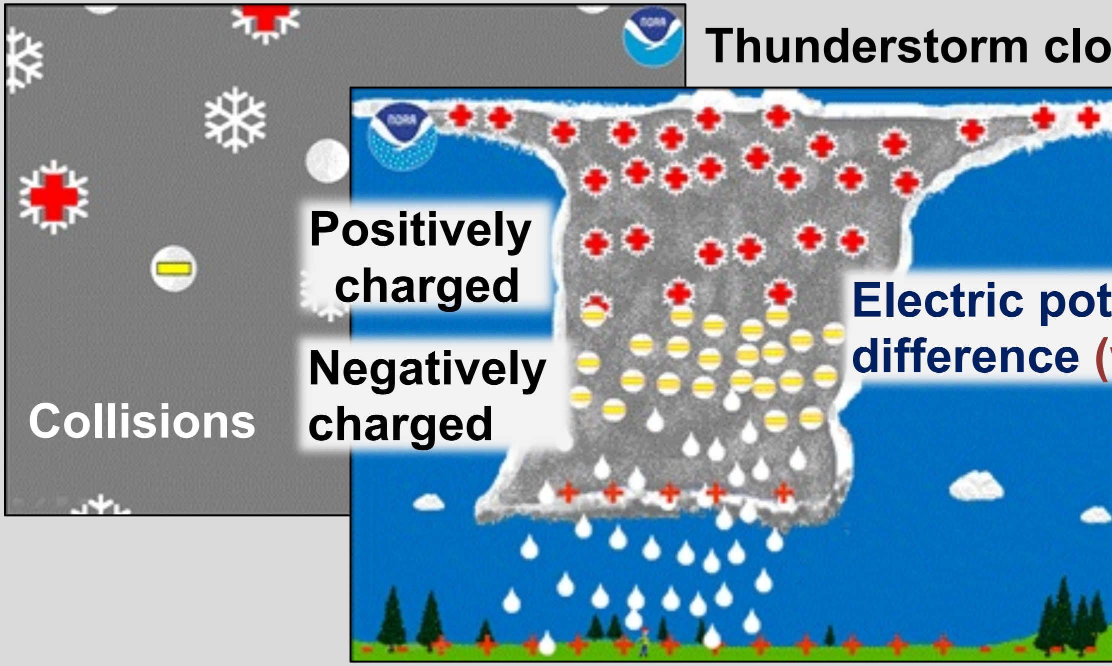
Like charges

Section 23.6



Unequal charges

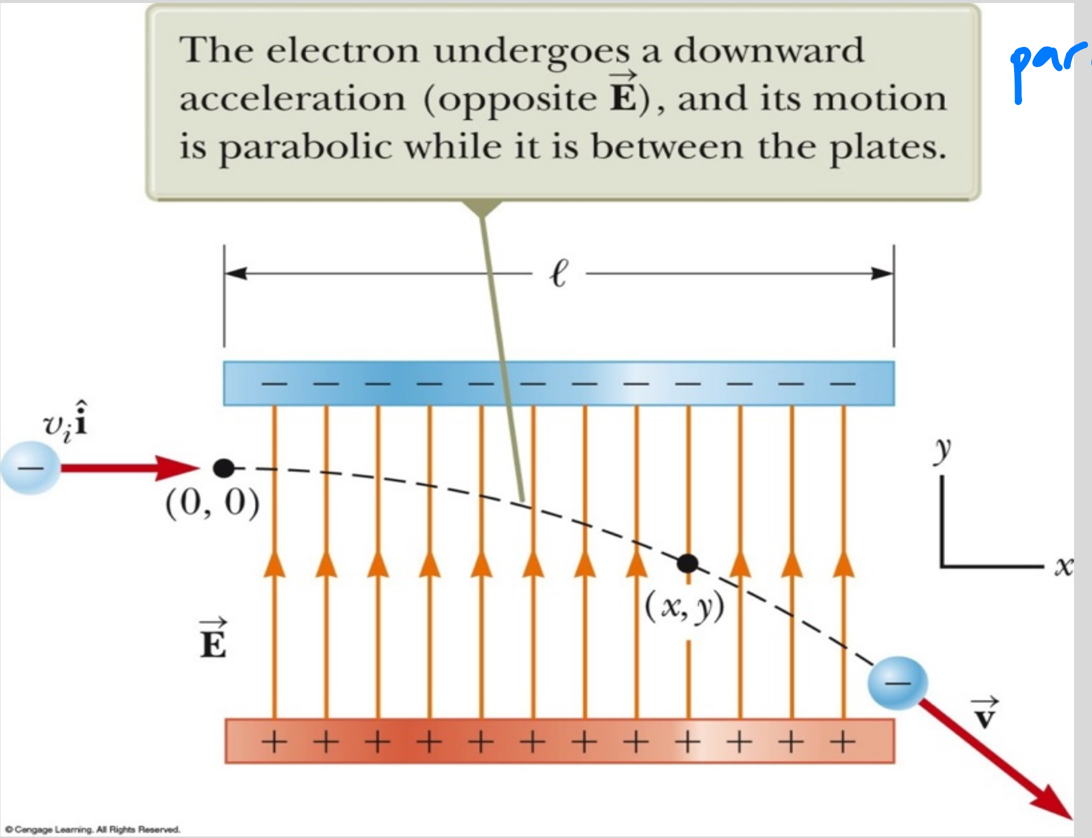
Lightning



https://en.wikipedia.org/wiki/Electrostatic_discharge
https://en.wikipedia.org/wiki/Lightning

Electron in a Uniform Field

$$\vec{\mathbf{F}}_e = q\vec{\mathbf{E}} = m\vec{\mathbf{a}} \qquad \vec{\mathbf{a}} = \frac{q\vec{\mathbf{E}}}{m}$$

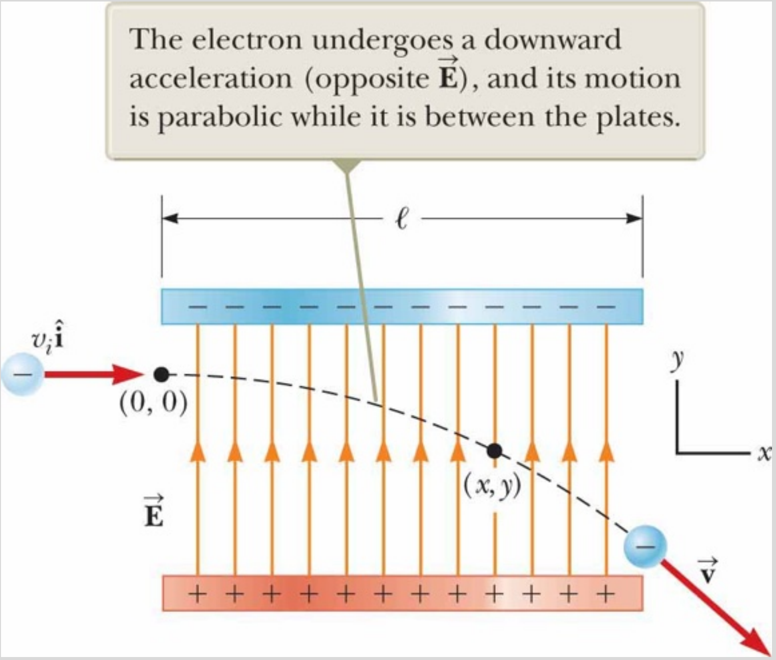


parabola: 拋物線

Section 23.7

Example 23.8: An Accelerated Electron

- An electron enters the region of a uniform electric field as shown in the figure, with $v_i = 3\times10^6$ m/s and E = 200 N/C. The horizontal length of the plates is $\ell = 0.100$ m.
- (A) Find the acceleration of the electron while it is in the electric field
- (B) Find the time at which the electron leaves the field.
- (C) What is the electron vertical position when it leaves the field? (Assuming yi(0) = 0)



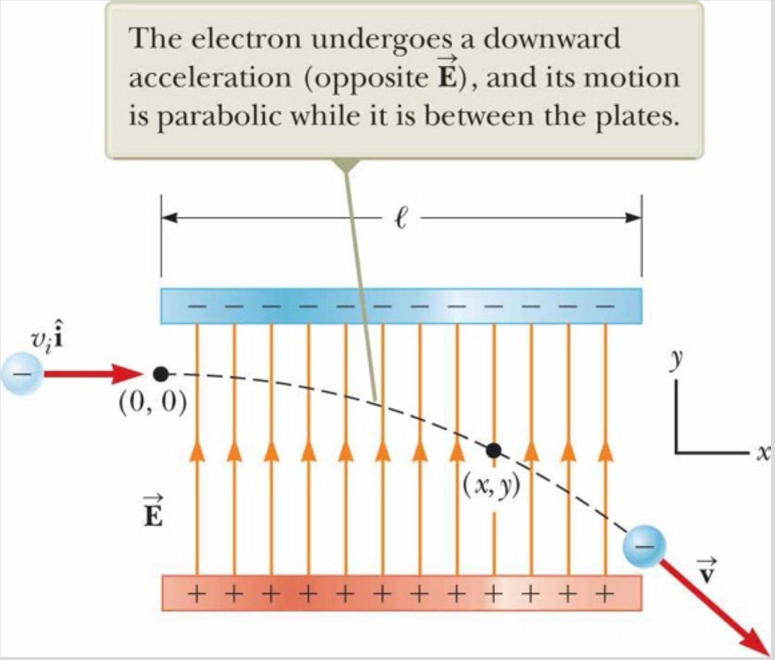
$$a_y = -\frac{eE}{m_e}$$

(A) $$a_y = -\frac{(1.60\times10^{-19}\ \mathrm{C})(200\ \mathrm{N/C})}{9.11\times10^{-31}\ \mathrm{kg}}$$

$$= \boxed{-3.51\times10^{13}\ \mathrm{m/s^2}}$$

Example 23.8: An Accelerated Electron

(B) $$t = \frac{\ell - 0}{v_x} = \frac{0.100 \text{ m}}{3.00\times10^{6} \text{ m/s}} = \boxed{3.33\times10^{-8} \text{ s}}$$



(C) $$y_f = y_i + \left(v_{yi}t + \frac{1}{2}a_y t^2\right)$$

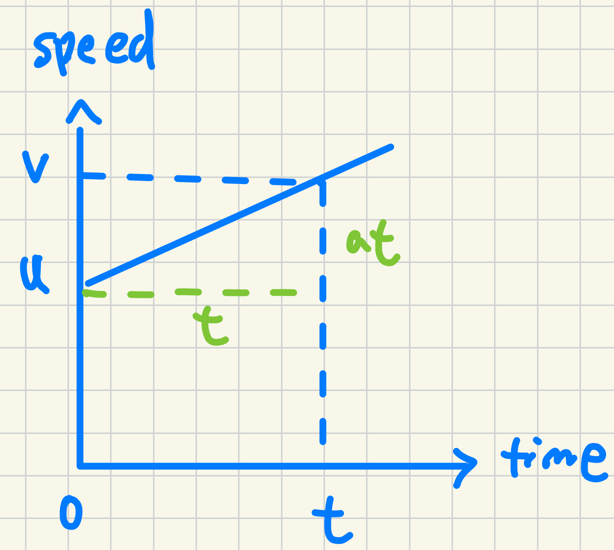
$$y_f = 0 + 0 + \frac{1}{2}\left(-3.51\times10^{13} \text{ m/s}^2\right)\left(3.33\times10^{-8} \text{ s}\right)^2$$
$$= -0.0195 \text{ m} = \boxed{-1.95 \text{ cm}}$$

Formulas for Uniformly - Accelerated Motion

1. $v = u + at$

2. $s = ut + \frac{1}{2}at^2$

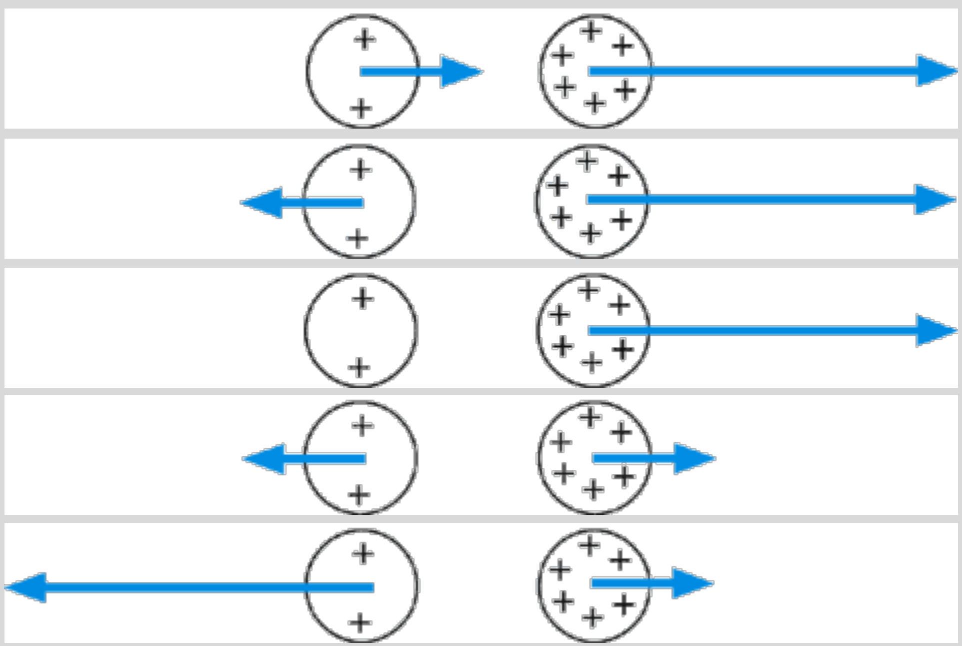
3. $v^2 = u^2 + 2as$



Quick quiz

- The diagrams below show two uniformly charged spheres. The charge on the right sphere is 3 times as large as the charge on the left sphere.
- (a) Which force diagram best represents the magnitudes and directions of the electric forces on the two spheres? d
- (b) Which choice best represents the magnitudes and directions of the electric field vectors created by one sphere at the other sphere? e

(a)
(b)
(c)
(d)
(e)



Answer (a): (d)
Answer (b): (e)

This Lecture

- About Me
  - My Research
- About “General Physics II”
  - Fascinating Electricity & Magnetism

Electric fields

- Electric charges
- Conductors and Insulators
- Coulomb’s Law
- Electric fields