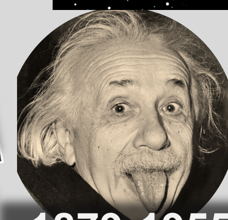
Lecture 02 – chapter 25
Electric Potential

蔡尚岳
政治大學應用物理所

Before Lecture

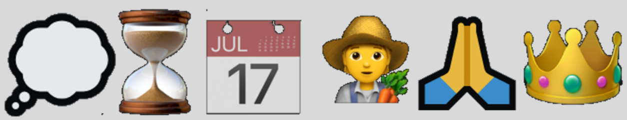
- 同學問: 重力能影響時間，跟萬有引力型式很像的庫倫力?

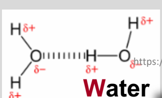
萬有引力



1879-1955
Einstein

重力是時空幾何





Biology

Chemistry

電學 **Week 1-12** 磁學

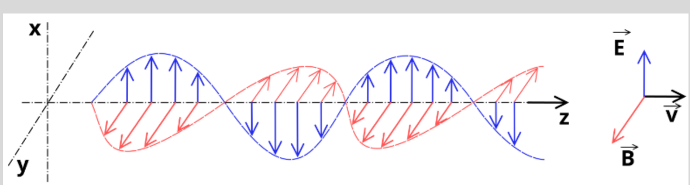
114-1 Modern Physics
相對論+量子力學

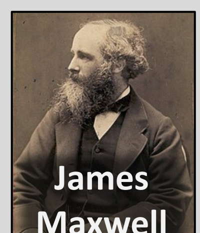
Week 14-15

光是什麼?

Week 13

電磁波





$$\nabla \cdot E = \frac{\rho}{\varepsilon_0}$$
$$\nabla \cdot B = 0$$
$$\nabla \times E = -\frac{\partial B}{\partial t}$$
$$\nabla \times B = \mu_0 (J + \varepsilon_0 \frac{\partial E}{\partial t})$$

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

Before Lecture

1. 內外平衡
2. 外面低壓 ✓
3. 外面高壓

分析，拆解(大->小問題)

- 同學問：人體在無壓力情況會爆炸嗎？

物理連結生活，哪裡有？

大氣壓力下降，導致氧氣的分壓降低

高山症的分類

急性高山症：

Acute Mountain Sickness (AMS)

通常在抵達高山後的1~12小時出現。臨床的症狀有：頭痛，伴隨有以下任一項：虛弱無力；腸胃道症狀：噁心、嘔吐、食慾不振；頭暈頭昏；睡眠不佳。症狀通常在24~48小時適應後緩解，或因使用氧氣及止痛或止吐藥而解除。

高海拔腦水腫：

High Altitude Cerebral Edema (HACE)

高海拔腦水腫一旦出現會快速導致死亡，通常在出現急性高山症 (AMS) 後出現。症狀有：協調能力喪失、步態不穩或意識狀態改變。可以請受試者在平坦地面上，腳跟緊接著腳尖走一直線，大約走5公尺，正常者是不會搖晃或跌出線外，若有則要提高警覺。

高海拔肺水腫：

High Altitude Pulmonary Edema (HAPE)

高海拔肺水腫也是一旦出現會快速導致死亡的疾病，而且進展到死亡的速度可能比高海拔腦水腫更快。臨床上可以單獨出現或合併高海拔腦水腫一起出現。臨床症狀有：休息狀態下有呼吸不適、咳嗽、虛弱無力或運動能力喪失、胸悶。

減壓症 (潛水夫病)

上述提到的風險中，減壓症算是潛水中最普遍的意外事件之一。**減壓症，俗稱潛水夫病或沉箱病，英文為Decompression sickness (縮寫：DCS) 。其發生的機轉是因為在潛水的過程中，隨著外界壓力的增加，會增加氣體在血液中的溶解率，呈現過飽和的狀態。在結束浮潛向上爬升的過程中，氣體則是會從血液中解離出來 (尤其是氮氣) 。**

一般正常情況下，溶解出的氣體會隨著我們的呼吸慢慢排出體外，並不會對身體造成傷害。但是若爬升速度太快，氣體短時間內快速游離出來，來不及排出體外，則會堆積在於組織間隙，直接對細胞造成傷害或阻礙血液循環造成缺血和缺氧。在分類上可分為第一型、第二型及慢性型等三種。

第一型減壓症，症狀較為輕微，常見的表現如四肢關節疼痛，皮膚紅癢。第二型較為嚴重，全身都會受到影響，包含全身倦怠、肢體無力或麻木、頭暈、噁心、嘔吐、胸悶胸痛、呼吸困難、視力模糊、小便失禁…等。根據觀察，不論第一型或第二型的發病時間 (onset) 都很快，大多在結束浮潛的6小時內產生，較嚴重的甚至會在結束後的數分鐘內出現症狀。根據統計，潛水深度越深、年紀越大、下潛次數越多、爬升速度過快的人身上較容易發生症狀。

減壓症大多發生於不當減壓而產生。例如不依減壓表規定快速上升，有時亦有可能遇到海洋強流而將淺水者快速往上帶。另有在太接近的時間內重複潛水，亦會增加減壓症發生機率。所以，初學者需在有經驗的潛水教練指導下作適當的下潛極上浮的動作。而常潛水的人也應該謹記並遵守減壓的流程及避免短時間內重複潛水。

高壓氧治療減壓症

若真的發生減壓症，在後續處置上，狀況輕微的人在休息後，隨著氣體慢慢吸收排出體外，大多會緩解。但是第二型或是症狀較嚴重的病人則需要就醫治療。目前減壓症的標準治療方為是高壓氧治療，將病人放置於高壓艙內並給予純氧。

https://www.cmuh.cmu.edu.tw/NewsInfo/NewsArticle?no=4610
https://www.cmuh.cmu.edu.tw/NewsInfo/NewsArticle?no=4611

中國醫藥大學附設醫院
China Medical University Hospital

Before Lecture

- 最近的新聞: 微重力環境

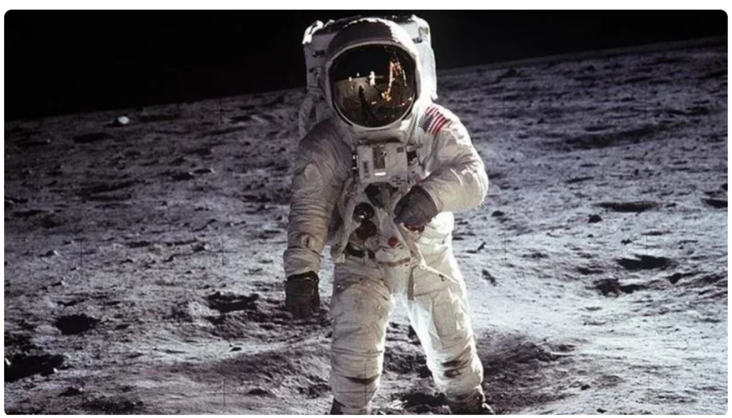
SETN三立新聞網 | 99.8k 人追蹤 ☆ 追蹤

忘記怎走路！滯留2太空人身體「失去基本能力」

三立新聞網
2025年2月13日

記者陳采蔚 / 綜合報導

NASA最新宣布，滯留太空超過半年的2名太空人，終於要在3月底提早返家。CNN指出，2人疑似因滯留太空時間過長，身體已失去基本能力，太空人威廉絲透露，由於生活在太空時間非常久，她幾乎忘記怎麼正常走路，專家分析，微重力對人體影響大，一旦長時間生活在太空，不僅會讓身體承受巨大壓力，甚至有部分太空人在返家後，視力永久受損。



NASA滯留太空超過半年的2名太空人，將在3月底返家。（示意圖 / 翻攝自pixabay）

主播：「兩名被困在國際太空站的太空人，現在可能很快就能返家。」

8天任務，沒想到竟變成超過半年，還記得這2名NASA太空人原本預計去年6月就要返回地球，卻因飛船推進器故障被迫延後返航，現在美國NASA證實，他們在3月底確定能提早回家，但這趟漫長任務卻讓2名太空人身體亮紅燈。

太空人Suni Williams（2024.11.12）：「在這裡，我們（身體狀況）的確出現很多變化，你應該聽說過體液變化，太空人的頭看起來會大一點，這就是因為體液的關係。老實說我在這裡夠久了，現在我正試著回想走路的感覺，在這裡我沒走過路、沒坐過也沒躺過。」

太空人威廉斯透露，她已經失去部分身體機能，就連怎麼走路都已忘記，儘管她強調2人都保持運動習慣，但長期生活在微重力環境，已讓他們的身體吃不消。

NASA太空人Michael Barrat：「我在太空完全無法這樣。」

根據規定，太空人每日必須做2小時的運動訓練，包含跑步機或是固定腳踏車和阻力訓練，因為一旦沒有維持肌肉力量，身體很快就會出狀況。

NASA人類研究計畫辦公室主任Dr John Charles：「當你處於失重狀態，人體血液開始發生變化，平衡器官的功能會立即感覺到失重感。」

研究指出，光是在太空待上3天，人體細胞和免疫系統就會發生變化，加上飛行對身體造成壓力，導致肌肉和身體無法達成平衡，甚至有太空人返家後視力永久受損。

太空人Suni Williams：「我必須反過來（睡覺），我的感覺並沒有跟我說，我現在是倒過來睡覺的。」

專家分析，95%的太空人在返家幾個月內都能恢復正常，但必須是短期飛行才不會對健康造成重大風險，如今滯留太空超過半年的2人即將返家，身體究竟承受多大壓力，外界難以想像。

https://tw.news.yahoo.com/%E5%BF%98%E8%A8%98%E6%80%8E%E8%B5%B0%E8%B7%AF-%E6%BB%AF%E7%95%992%E5%A4%AA%E7%A9%BA%E4%BA%BA%E8%BA%AB%E9%AB%94-%E5%A4%B1%E5%8E%BB%E5%9F%BA%E6%9C%AC%E8%83%BD%E5%8A%9B-141900798.html

Before Lecture

- 上週下課後，有位同學問，如果把高斯定理用在導體的話？高中學導體$E_{inside} = 0$

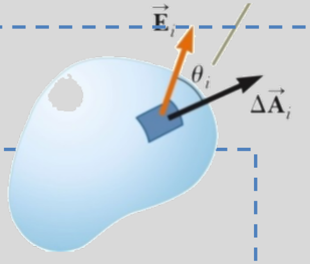
  另一位同學接著說，這是不是電梯(同學是說飛機，那還有網路訊號覆蓋等因素)裡面收不到訊號的原因？

  1.掌握上週剛學到的物理
  2.連結高中學到的物理
  3.提出超前進度的問題
  這是為什麼問得非常好

注意: 我並沒有隨便稱讚
分析, 拆解(大->小)

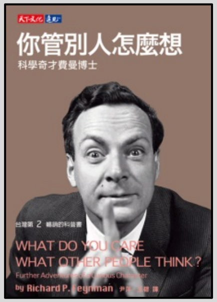
Previous Lecture

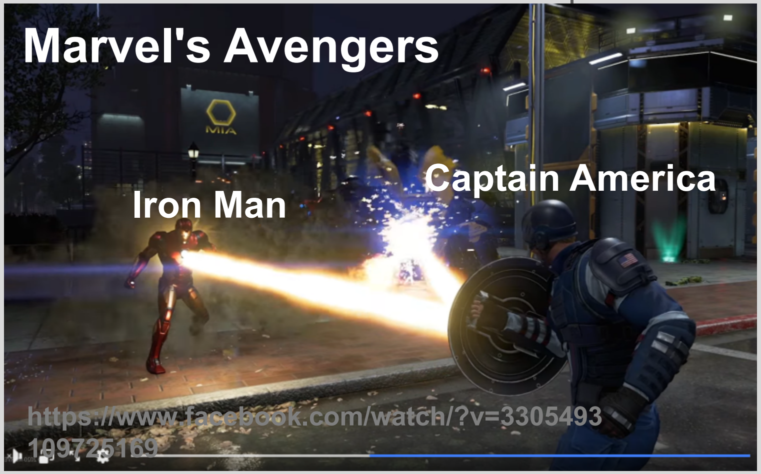
- A Story That Changed My Life
- Electric Fields of Continuous Charge Distributions
  - Uniform Charged Ring
  - Uniform Charged Disk
- Electric flux



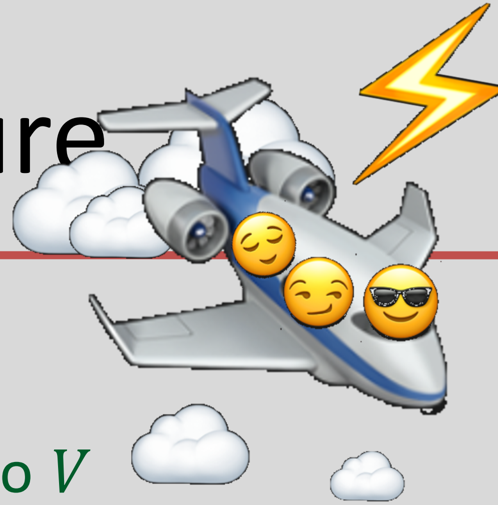
- Gauss's Law
  - Sphere, Line, Plane

Convenient for calculating the electric fields of highly symmetric charge distributions





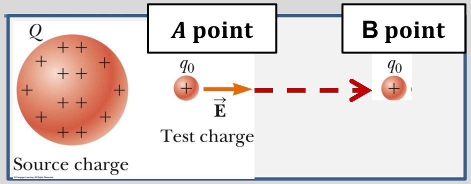
This Lecture



- Electric Potential Energy U

  Electric Potential V (Volt)

From E to V

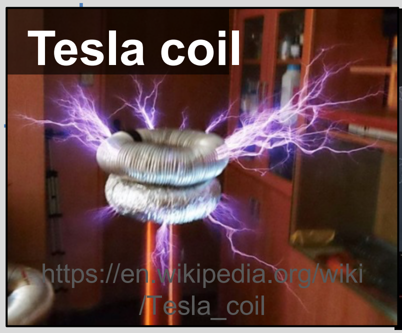


- Electric Potential Difference ΔV In a Uniform Electric Field E
- Electric Potential V Due to Point Charges

- Find the Electric Field E from the Electric Potential V
  - Uniform Charged Ring
  - Uniform Charged Disk

From V to E

- Conductors in Electrostatic Equilibrium



Electric Potential Energy

- Electrostatic force is **conservative (保守力)**
- The work done within the charge-field system by the electric field on the charge

$(\vec{a} \cdot \vec{b} = |\vec{a}||\vec{b}|\cos\theta)$

$$\vec{F} \cdot d\vec{s} = q_0\vec{E} \cdot d\vec{s}$$

- **The potential energy (電位能)** of the charge-field system

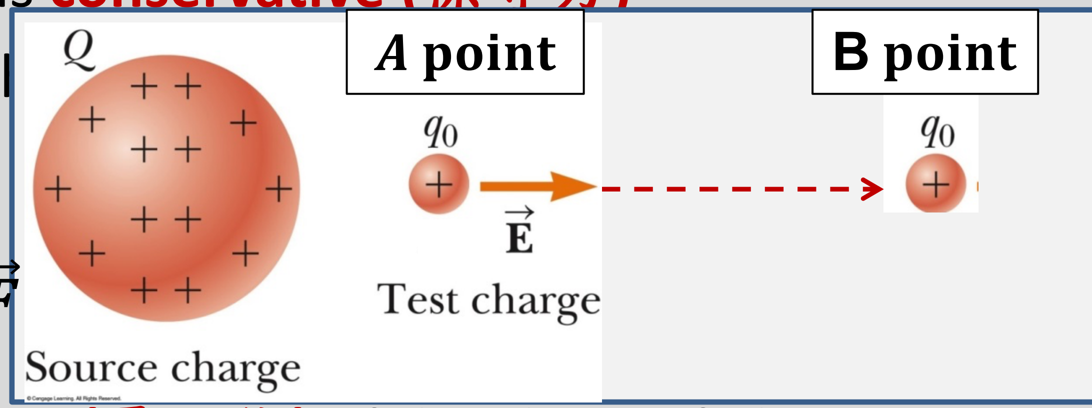
$$\Delta U = -q\int_A^B \vec{E} \cdot d\vec{s}$$

  - Because the force is conservative, the line integral does not depend on the path taken by the charge

Electric Potential Energy

- Electrostatic force is **conservative (保守力)**
- The work done wit
field on the charge

$\vec{F}$



- **The potential energy (電位能)** of the charge-field system

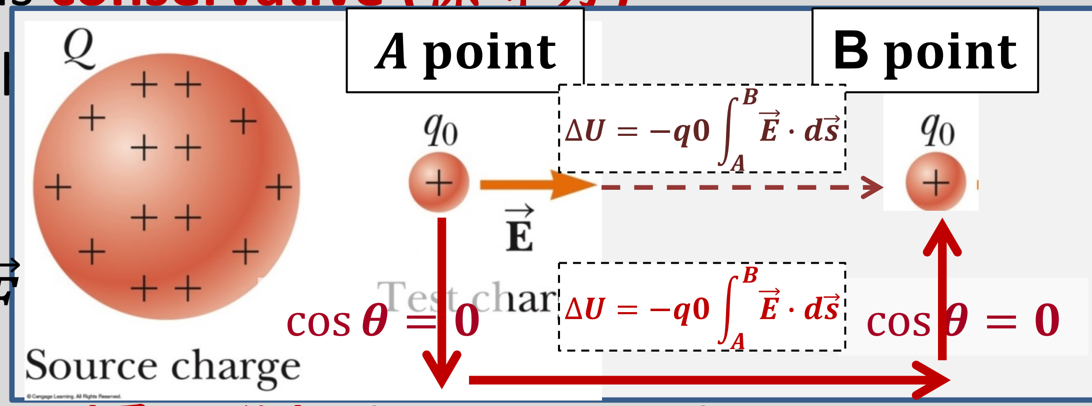
$$\Delta U = -q\int_A^B \vec{E}\cdot d\vec{s}$$

  - Because the force is conservative, the line integral does not depend on the path taken by the charge

Electric Potential Energy

- Electrostatic force is **conservative (保守力)**
- The work done wit
  field on the charge

$\vec{F}$



- **The potential energy (電位能)** of the charge-field system

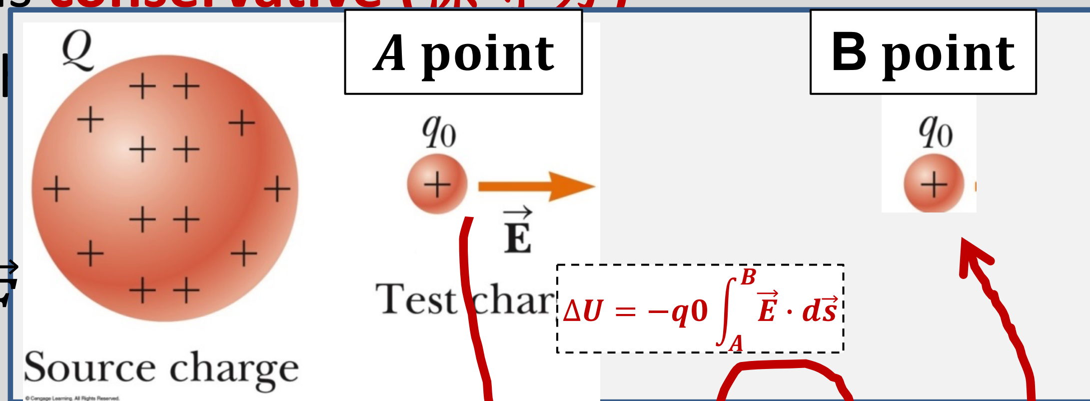
$$\Delta U = -q \int_A^B \vec{E} \cdot d\vec{s}$$

  – Because the force is conservative, the line integral does not depend on the path taken by the charge

Electric Potential Energy

- Electrostatic force is **conservative (保守力)**
- The work done wit
field on the charge

$\vec{F}$



- **The potential energy (電位能)** of the charge-field system

$$\Delta U = -q \int_A^B \vec{E} \cdot d\vec{s}$$

– Because the force is conservative, the line integral does not depend on the path taken by the charge

Electric Potential (電位)

- A charged particle moving in an electric field will experience a change in potential (potential difference)

$$\Delta V \equiv \frac{\Delta U}{q} = -\int_A^B \vec{E} \cdot d\vec{s} \qquad (25.2)\ (25.3)$$

  - The potential energy per unit charge, U/q_0
  - Has a value at every point in an electric field
  - Scalar quantity, Units: **V (voltage, volt, 伏特)**
- Electron-Volts (電子伏特)
  - Unit of energy commonly used in atomic and nuclear physics
  - 1 eV = 1.60×10^{-19} C·V = 1.60×10^{-19} J

Electric Potential (電位)

- A charged particle moving in an electric field will experience a change in potential

$$\Delta V \equiv \frac{\Delta U}{} = -\int^{B} \vec{E} \cdot d\vec{s} \qquad \textbf{(25.2)}$$

電荷源=>電場 $\vec{\mathbf{E}} = k_e \sum_i \frac{q_i}{r_i^2} \hat{\mathbf{r}}_i$ 　純量 $V = k_e \sum_i \frac{q_i}{r_i}$

=>電場中每一處都有其對應的電位(A>B)

=>A點跟B點之間的電位差 $\Delta V = -\int_A^B \vec{E} \cdot d\vec{s}$

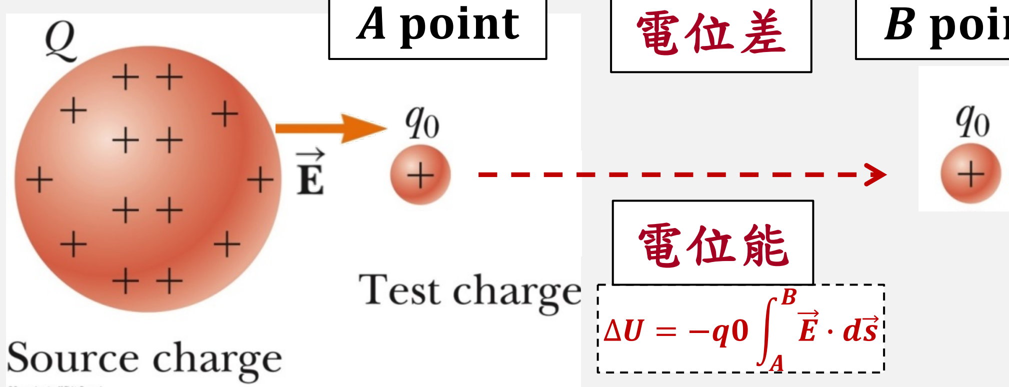
電荷$q0$在A點，受到$q0\vec{E}$的力，如果將它從A移動到B，因為經歷電位差ΔV，所以需要做功，=電位能變化$\Delta U = q0\Delta V$。

- Ele

– ysics

–

A point 　**電位差** 　**B point**

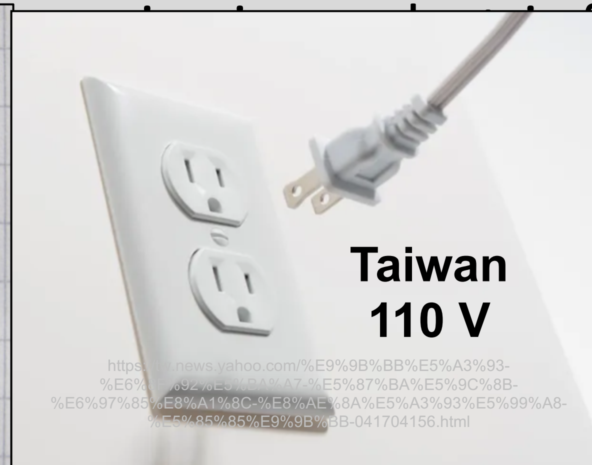


電位能

$$\Delta U = -q0 \int_A^B \vec{E} \cdot d\vec{s}$$

Electric Potential (電位)

•



=>A點跟B點之間的電位差 $\Delta V = -\int_A^B \vec{E}\cdot d\vec{s}$

壓電位差

=電位能

• Ele

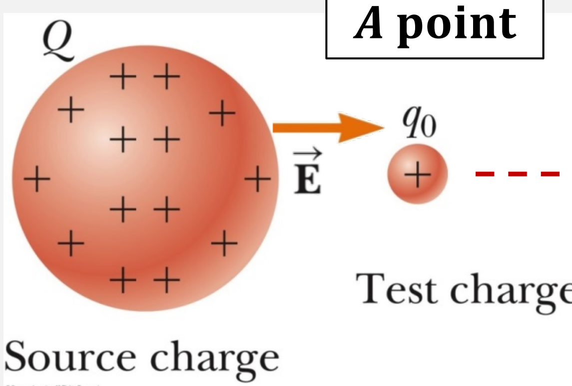
–

–

A point

電位差

B



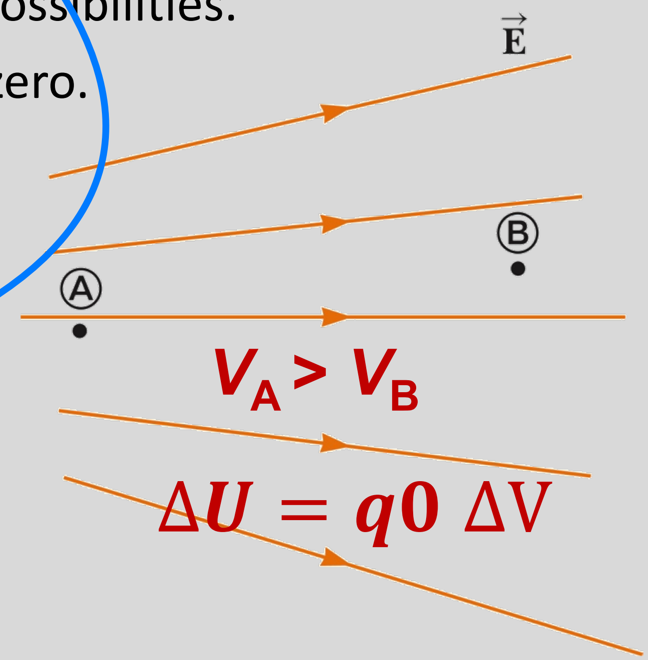
電位能

$\Delta U = -q0\int_A^B \vec{E}\cdot d\vec{s}$

Quick Quiz 25.1

- In Figure 25.1, two points A and B are located within a region in which there is an electric field.
- b **(i)** How would you describe the potential difference $\Delta V = V_B - V_A$?
- a **(ii)** A negative charge is placed at A and then moved to B. How would you describe the change in potential energy of the charge–field system for this process? Choose from the same possibilities.
- (a) It is positive. (b) It is negative. (c) It is zero.

$$\Delta U = -q\,\vec{E}\cdot d\vec{s}$$



$$V_A > V_B$$

$$\Delta U = q0\ \Delta V$$

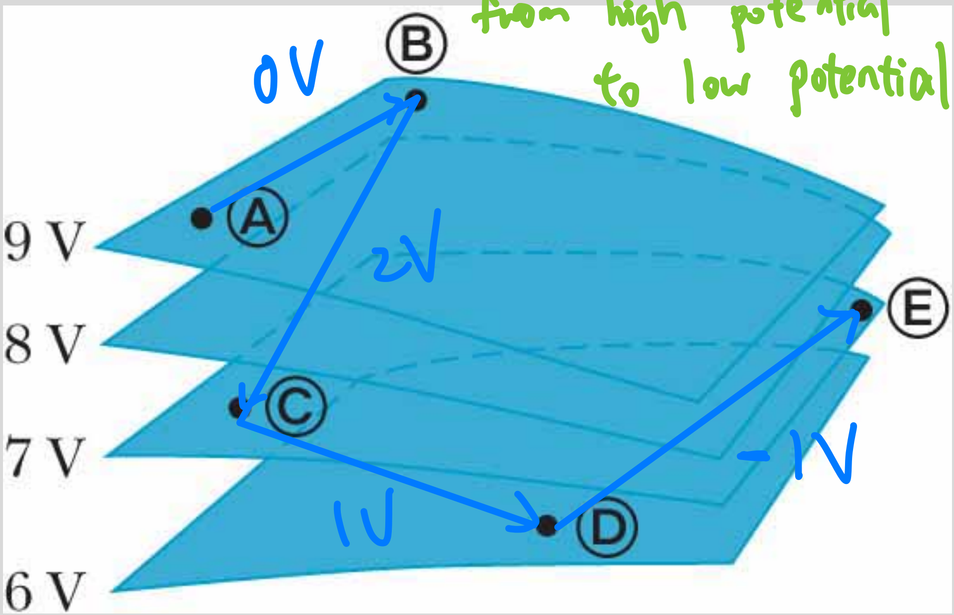
- **Answer: (i) (b) (ii) (a)**

Quick Quiz 25.2

- The labeled points in the figure are on a series of equipotential surfaces associated with an electric field. Rank (from greatest to least) the work done by the electric field on a positively charged particle that moves from A to B, from B to C, from C to D, and from D to E.

The electric field points from high potential to low potential

$\vec{E}$



B to C, 2V

C to D, 1V

A to B, 0V

D to E -1V

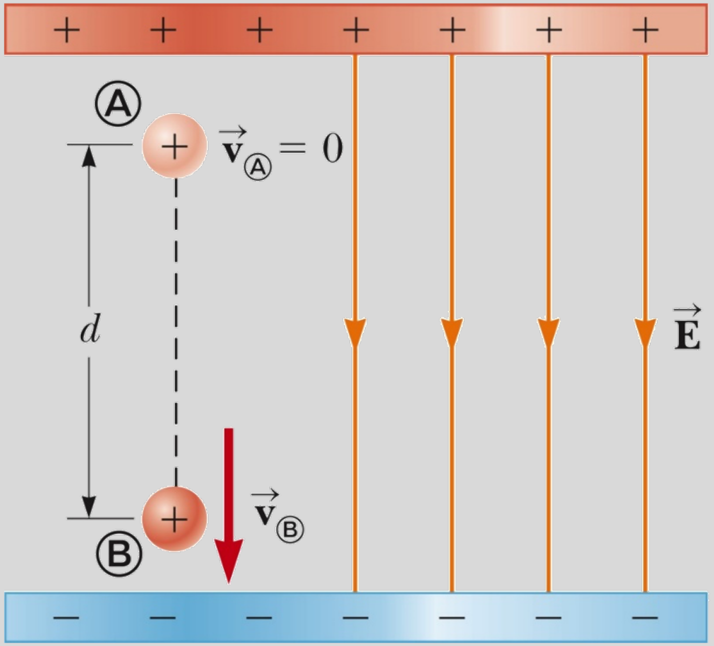
$$\boxed{W \text{ (work done)} = -q\,\Delta V}$$

Example 24.2

"conservation of mechanical energy": Within a closed system where only conservative forces are acting, the total mechanical energy (kinetic energy K and potential energy U_E) remains constant

- A proton is released from rest at point A in a uniform electric field that has a magnitude of 8.0 × 10⁴ V/m (Fig. 25.6). The proton under-goes a displacement of magnitude *d* = 0.50 m to point B in the direction of E. Find the speed of the proton after completing the displacement.

$$\Delta K + \Delta U_E = 0 \Rightarrow \left(\frac{1}{2}mv^2 - 0\right) + e\Delta V = 0$$

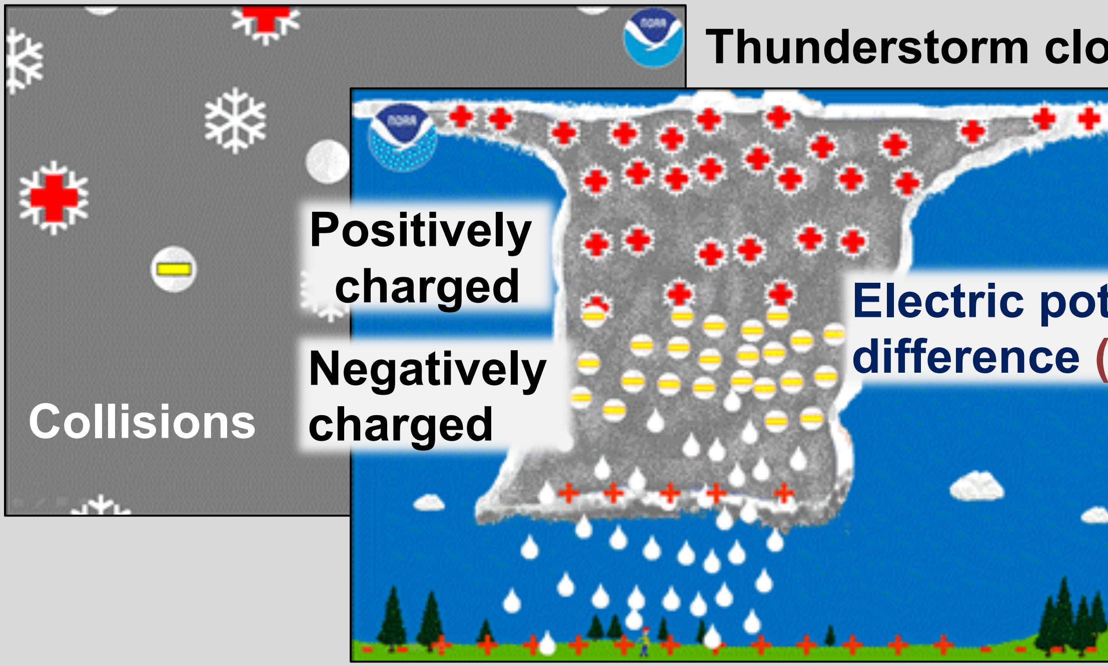


$$\Rightarrow v = \sqrt{\frac{-2e\Delta V}{m}} = \sqrt{\frac{-2e(-Ed)}{m}} = \sqrt{\frac{2eEd}{m}}$$

$$\Rightarrow v = \sqrt{\frac{2(1.6\times10^{-19}\ \text{C})(8.0\times10^{4}\ \text{V})(0.50\ \text{m})}{1.67\times10^{-27}\ \text{kg}}}$$

$$= \boxed{2.8\times10^{6}\ \text{m/s}}$$

Lightning



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

Potential Difference of a point charge (E is known)

$$V_B - V_A = -\int_A^B \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} \qquad \vec{\mathbf{E}} = \frac{k_e q}{r^2}\hat{\mathbf{r}}$$

$$\vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} = k_e \frac{q}{r^2}\hat{\mathbf{r}} \cdot d\vec{\mathbf{s}}$$

$$\hat{\mathbf{r}} \cdot d\vec{\mathbf{s}} = ds\cos\theta \qquad ds\cos\theta = dr$$

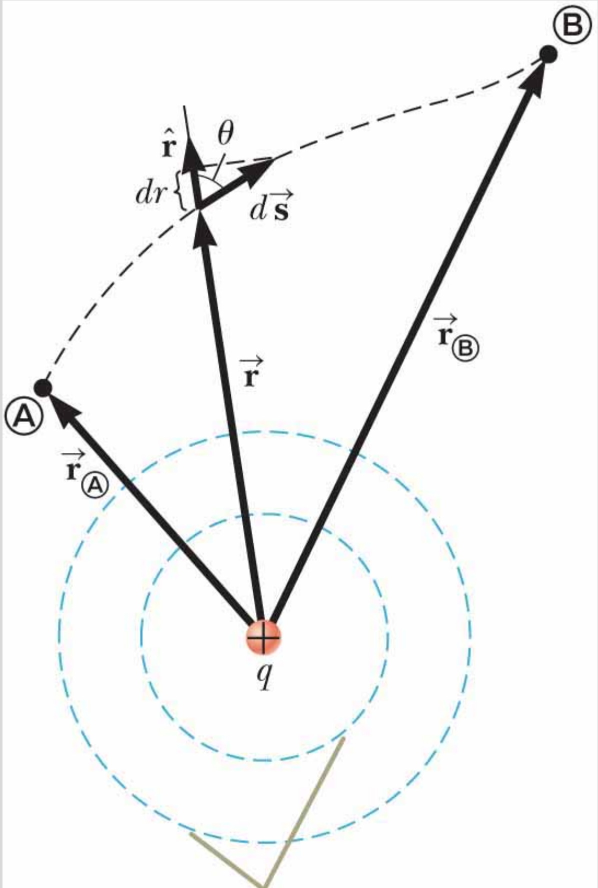
$$\vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} = k_e \frac{q}{r^2} dr$$

$$V_B - V_A = -k_e q \int_{r_A}^{r_B} \frac{dr}{r^2} = k_e \frac{q}{r}\Big|_{r_A}^{r_B}$$

$$V_B - V_A = k_e q\left[\frac{1}{r_B} - \frac{1}{r_A}\right]$$

F E

V U



The two dashed circles represent intersections of spherical equipotential surfaces with the page.

Section 25.2

$$V_B - V_A = -\int_A^B \vec{E} \cdot d\vec{s}$$

$$\vec{E} = \frac{k_e q}{r^2} \vec{r}$$

$$= -\int_A^B k_e \frac{q}{r^2} \hat{r} \cdot d\vec{s}$$

$$\hat{r} \cdot d\vec{s} = ds\cos\theta$$

$$= -\int_A^B k_e \frac{q}{r^2} ds\cos\theta$$

$$ds\cos\theta = dr$$

$$= -\int_A^B k_e \frac{q}{r^2} dr$$

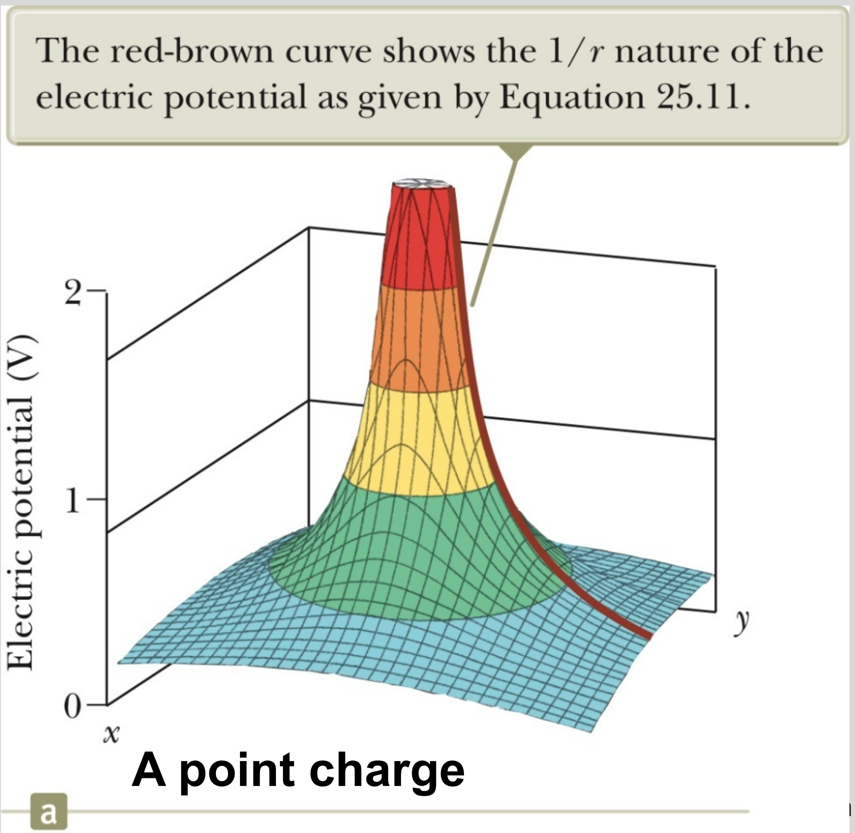
$$= k_e q \left[\frac{1}{r}\right]_A^B$$

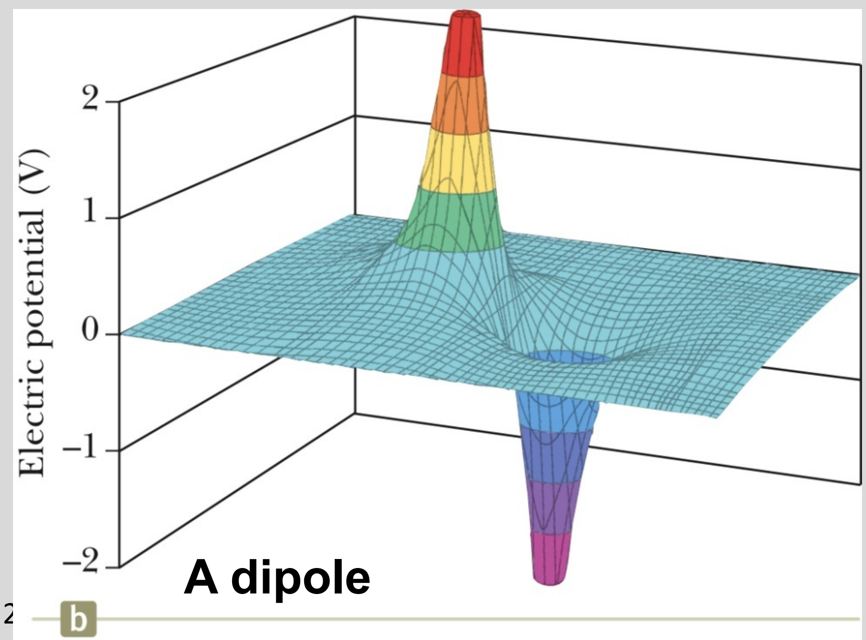
$$= k_e q \left(\frac{1}{r_B} - \frac{1}{r_A}\right]$$

Distribution of Electric Potential

- It is customary to choose a reference potential of $V = 0$ at $r = \infty$

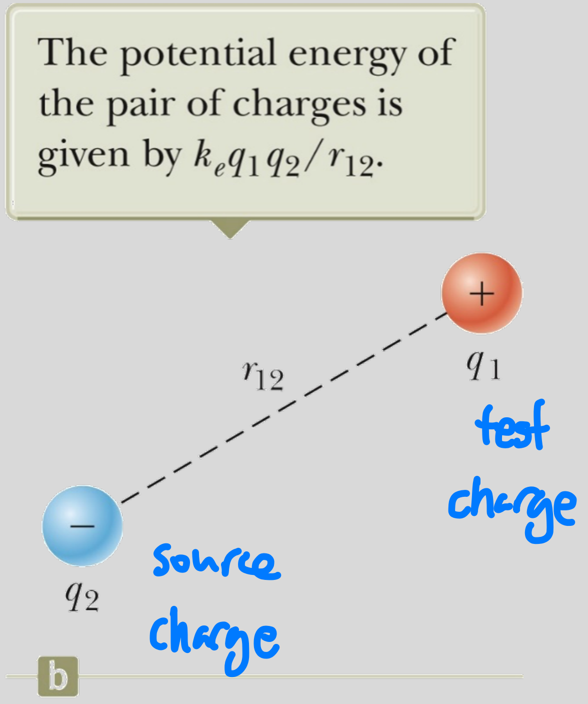
$$V = k_e \sum_i \frac{q_i}{r_i} \qquad \textbf{(25.12)}$$





QUIZ 25.3

- In the figure, take q2 to be a negative source charge and q1 to be the test charge. **(i)** If q1 is changed from positive to negative, what happens to the potential at the position of q1 due to q2? **(ii)** When q1 is changed from positive to negative, what happens to the potential energy of the two-charge system? Choose from the same possibilities.
- (a) It increases.
- (b) It decreases.
- (c) It remains the same.



- **Answer: (i) (c) (ii) (a)**

(i) $V = \dfrac{k_e q_2}{r_{12}}$, same

(ii) $U = \dfrac{k_e q_1 q_2}{r_{12}}$, $- \rightarrow +$

Example 25.3

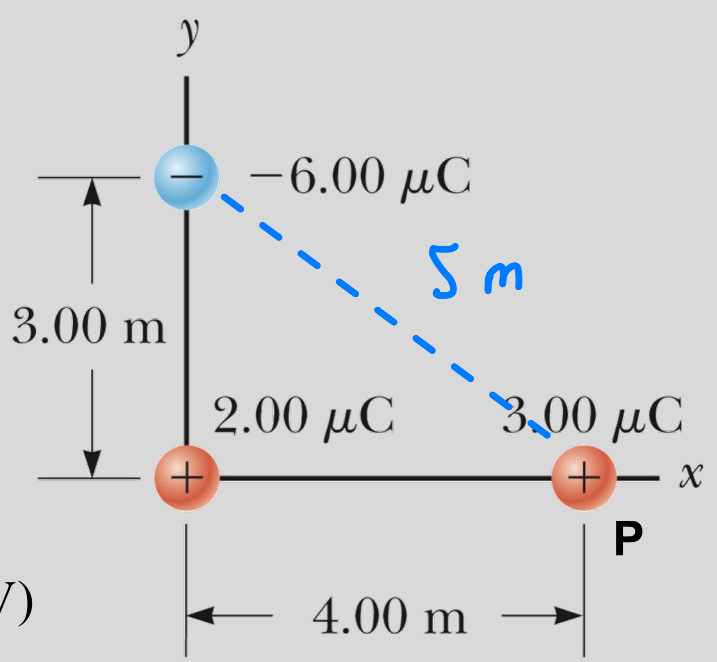
(A) Find the total electric potential at the point *P* (4.00, 0) m.

(B) Find the change in potential energy of the system of two charges plus a third charge q_3 = 3.00 μC as the latter charge moves from infinity to point *P*

(A) $$V_p = k_e\left(\frac{q_1}{r_1}+\frac{q_2}{r_2}\right)$$

$$V_p = (8.988\times10^{9}\ \mathrm{N\cdot m^2/C^2})\left(\frac{2.00\times10^{-6}\ \mathrm{C}}{4.00\ \mathrm{m}}+\frac{-6.00\times10^{-6}\ \mathrm{C}}{5.00\ \mathrm{m}}\right)$$

$$= -6.29\times10^{3}\ \mathrm{V}$$



(B) $$U_f = q_3 V_p$$

$$\Delta U = U_f - U_i = q_3V_p - 0 = (3.00\times10^{-6}\,\mathrm{C})(-6.29\times10^{3}\,\mathrm{V})$$

$$= \ -1.89\times10^{-2}\,\mathrm{J}$$

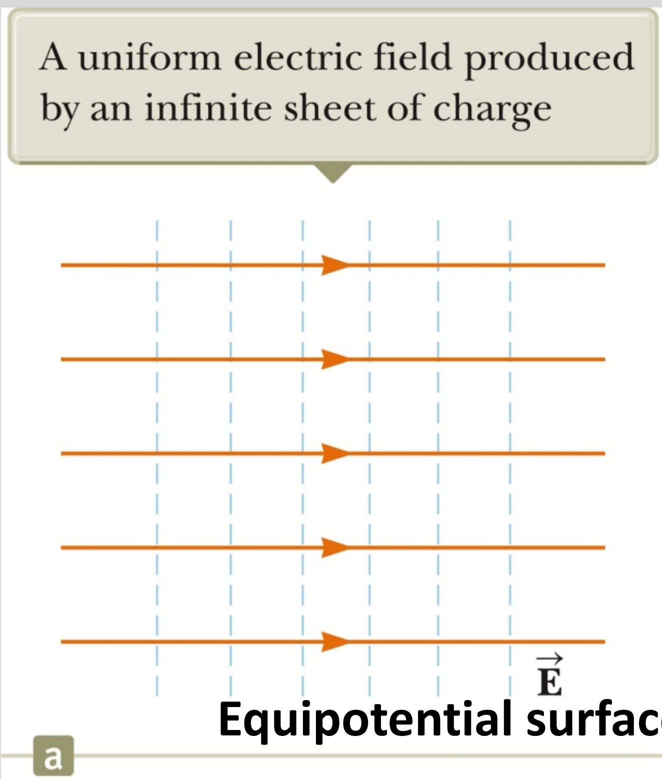
Finding *E* From *V*

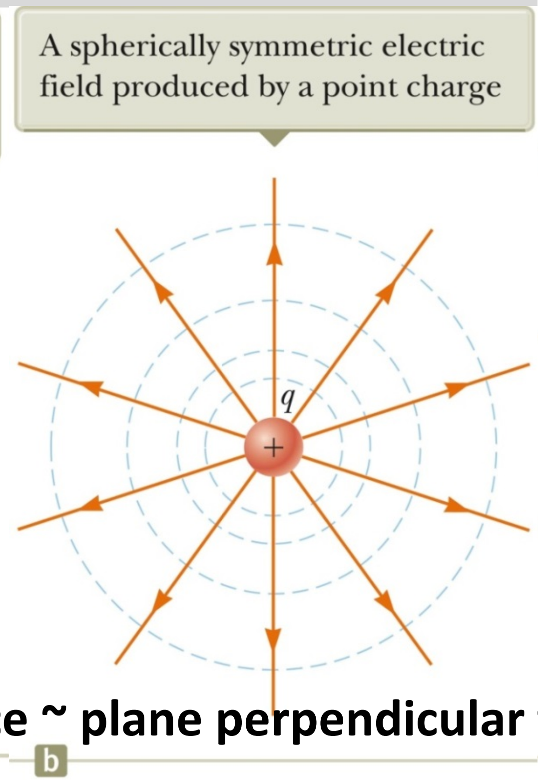
gradient

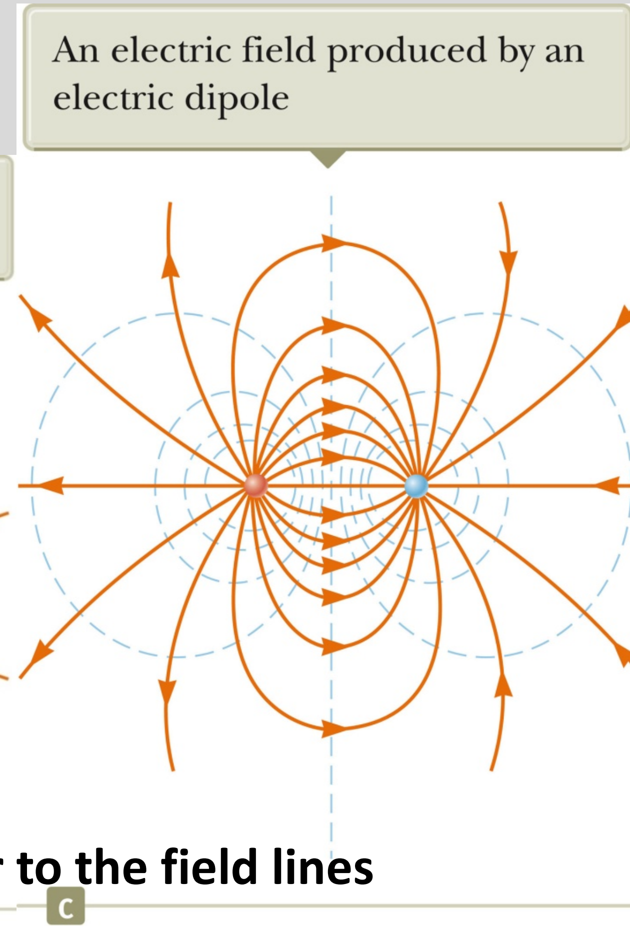
$$\vec{E} = -\nabla V, \quad E_x = -\frac{\partial V}{\partial x} \quad E_y = -\frac{\partial V}{\partial y} \quad E_z = -\frac{\partial V}{\partial z}$$

$$E_x = -\frac{dV}{dx}$$

$$E_r = -\frac{dV}{dr}$$







Equipotential surface ~ plane perpendicular to the field lines

Continuous Charge Distribution

(1° Find V
2° Find E from V)

- If the charge distribution is known, consider a small charge element dq

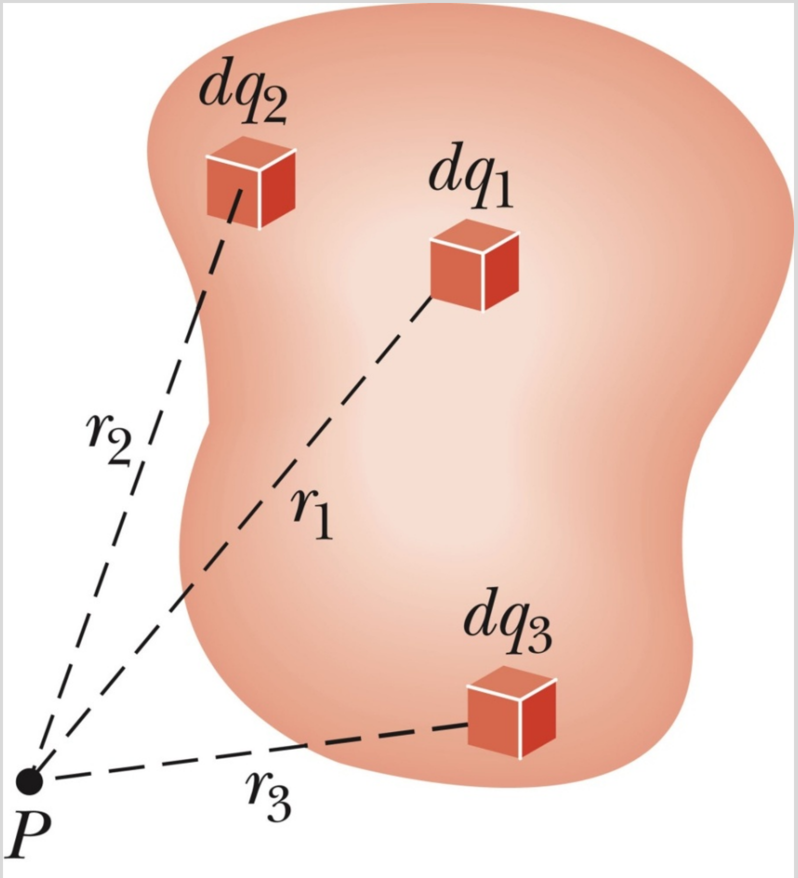
$$dV = k_e \frac{dq}{r} \quad \textbf{(25.19)}$$

$$V = k_e \int \frac{dq}{r} \quad \textbf{(25.20)}$$

  - The reference of $V = 0$ when P is infinitely far away from the charge distributions

- If the electric field is known,

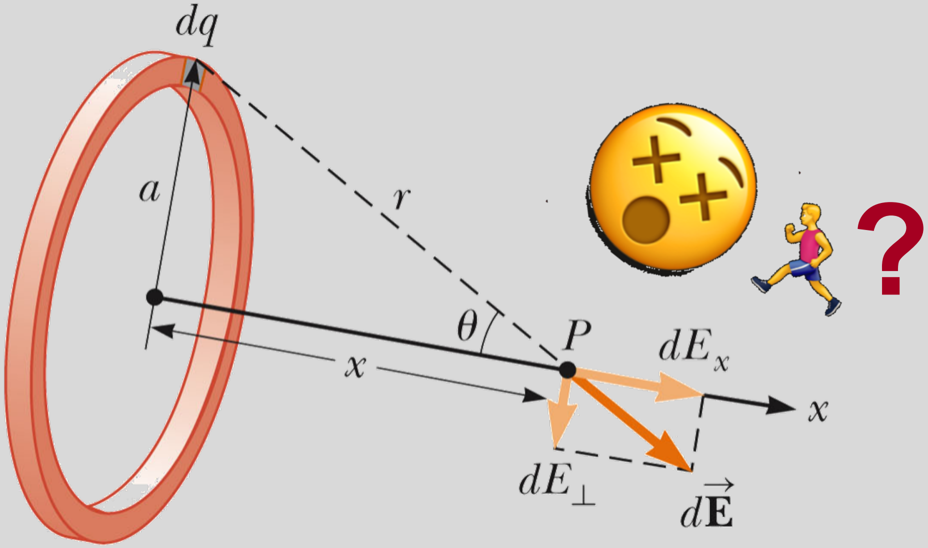
$$\Delta \boldsymbol{V} = -\int_{\boldsymbol{A}}^{\boldsymbol{B}} \vec{\boldsymbol{E}} \cdot \boldsymbol{d}\vec{\boldsymbol{s}}$$



Uniform Charged Ring

- A ring of radius *a* carries a uniformly distributed positive total charge *Q*

Case 1



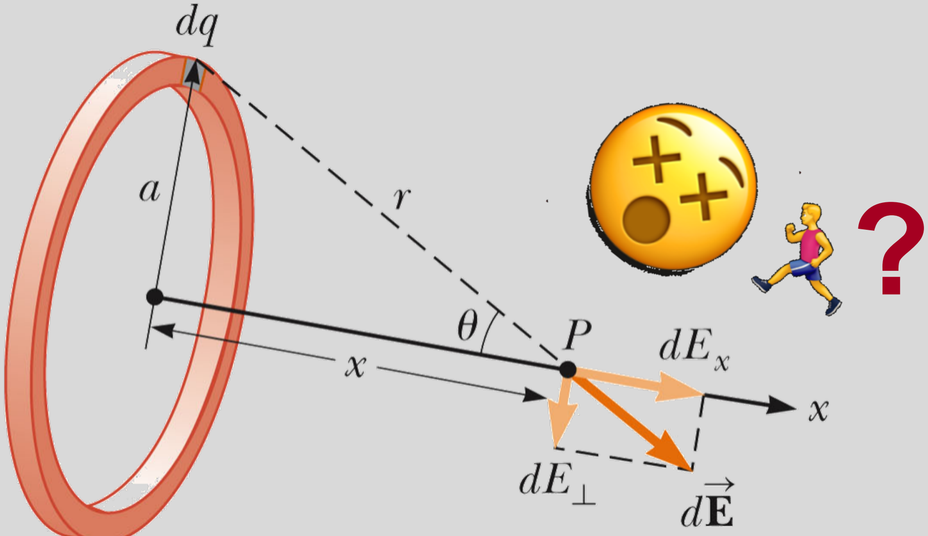
https://en.wikipedia.org/wiki/Alita:_Battle_Angel

Uniform Charged Ring

- A ring of radius *a* carries a uniformly distributed positive total charge *Q*

Case 1

Case 2



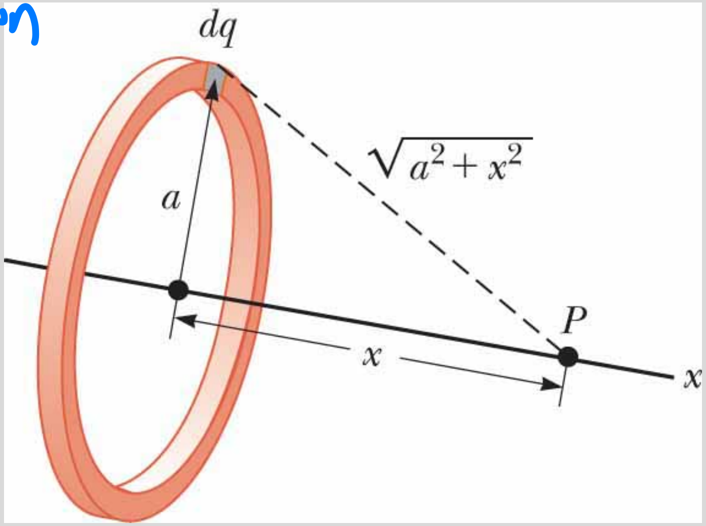
$E_x = \int$ k_e $(a^2 + x$ dq

$$(3) \quad E = \frac{k_e x}{(a^2 + x^2)^{3/2}} Q$$

V Due to a Uniformly Charged Ring

charge distribution $\downarrow$ V

1° $$V = k_e \int \frac{dq}{r} = k_e \int \frac{dq}{\sqrt{a^2+x^2}}$$



$$V = \frac{k_e}{\sqrt{a^2+x^2}} \int dq = \boxed{\frac{k_e Q}{\sqrt{a^2+x^2}}}$$

2° $$E_x = -\frac{dV}{dx} = -k_e Q \frac{d}{dx}\left(a^2+x^2\right)^{-1/2}$$

$$= -k_e Q\left(-\frac{1}{2}\right)\left(a^2+x^2\right)^{-3/2}(2x)$$

$$E_x = \boxed{\frac{k_e x}{\left(a^2+x^2\right)^{3/2}} Q}$$

V $\downarrow$ E

① $V = k_e \int \frac{dq}{\sqrt{a^2+x^2}} = \frac{k_e}{\sqrt{a^2+x^2}} \int dq = \frac{k_e Q}{\sqrt{a^2+x^2}}$

② $E = E_x = -\frac{dV}{dx} = -k_e Q \frac{d}{dx} (a^2+x^2)^{-\frac{1}{2}}$

$= -k_e Q \frac{d(a^2+x^2)^{-\frac{1}{2}}}{d(a^2+x^2)} \frac{d(a^2+x^2)}{dx}$

$= -k_e Q \left(-\frac{1}{2} (a^2+x^2)^{-\frac{3}{2}} \cdot 2x\right)$

$= \frac{k_e x}{(a^2+x^2)^{\frac{3}{2}}} Q$ ... Same answer as

in 1. Gauss's Law -

V for a Uniformly Charged Disk

1°

① $$dq = \sigma dA = \sigma\left(2\pi r\,dr\right) = 2\pi\sigma r\,dr$$

② $$dV = \frac{k_e dq}{\sqrt{r^2 + x^2}} = \frac{k_e 2\pi\sigma r\,dr}{\sqrt{r^2 + x^2}}$$

③ $$V = \pi k_e \sigma \int_0^R \frac{2r\,dr}{\sqrt{r^2 + x^2}}$$

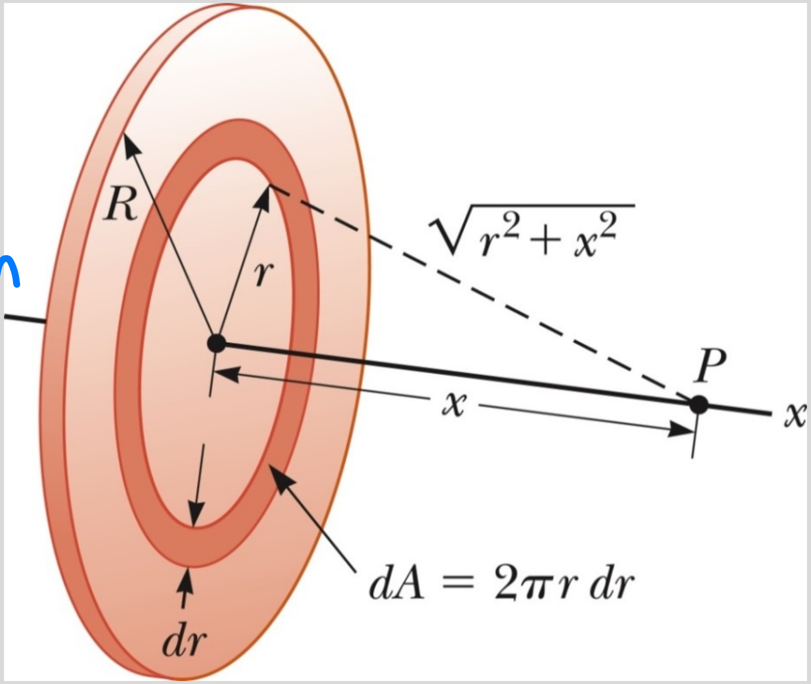
$$= \pi k_e \sigma \int_0^R \left(r^2 + x^2\right)^{-1/2} 2r\,dr$$

$$V = \boxed{2\pi k_e \sigma\left[\left(R^2 + x^2\right)^{1/2} - x\right]}$$

charge distribution

↓

V



2°

$$E_x = -\frac{dV}{dx} = 2\pi k_e \sigma\left[1 - \frac{x}{(R^2 + x^2)^{1/2}}\right]$$

Section 25.5

1° $dq = \sigma\, dA = \sigma\,(2\pi r\, dr) = 2\pi\sigma r\, dr$

2° $dV = \dfrac{k_e\, dq}{\sqrt{r^2+x^2}} = \dfrac{k_e 2\pi\sigma r\, dr}{\sqrt{r^2+x^2}}$

3° $V = \pi k_e \sigma \displaystyle\int_0^R \frac{2r\, dr}{\sqrt{r^2+x^2}}$

Let $u = r^2+x^2$

$\Rightarrow du = 2r\, dr$

$= \pi k_e \sigma \displaystyle\int_{x^2}^{R^2+x^2} u^{-\frac{1}{2}}\, du$

$= 2\pi k_e \sigma \left[u^{\frac{1}{2}} \right]_{x^2}^{R^2+x^2}$

$= 2\pi k_e \sigma \left[(R^2+x^2)^{\frac{1}{2}} - x \right]$

4°

$$E_x = -\frac{dV}{dx} = -\frac{d}{dx}\left(2\pi k_e \sigma\left[(R^2+x^2)^{\frac{1}{2}} - x\right]\right)$$

$$\left(\frac{d}{dx}(R^2+x^2)^{\frac{1}{2}} = \frac{d(R^2+x^2)^{\frac{1}{2}}}{d(R^2+x^2)}\,\frac{d(R^2+x^2)}{dx}\right.$$

$$\left. = \frac{1}{2}\cdot(R^2+x^2)^{-\frac{1}{2}}\cdot 2x = x(R^2+x^2)^{-\frac{1}{2}}\right)$$

$$= 2\pi k_e \sigma\left[1 - \frac{x}{\sqrt{R^2+x^2}}\right]$$

... Same answer as in 1. Gauss's Law

Quick Quiz 25.4

- In a certain region of space, the electric potential is zero everywhere along the *x* axis.
- a **(i)** From this information, what can you conclude that the *x* component of the electric field in this region?
- a **(ii)** Suppose the electric potential is +2 V everywhere along the *x* axis. From the same choices, what can you conclude about the *x* component of the electric field now?
- (a) zero, (b) in the positive *x* direction, or (c) in the negative *x* direction

$$E_x = -\frac{dV}{dx}$$

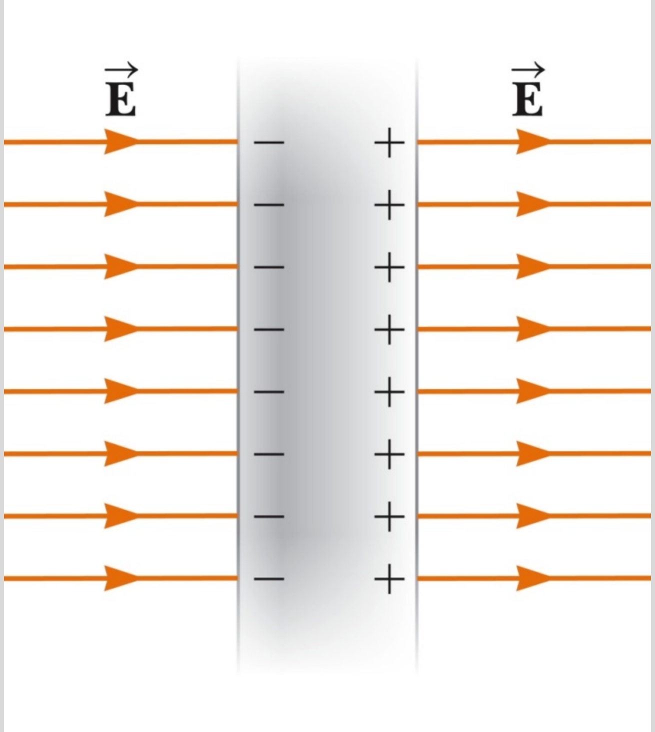
- **Answer: (i) (a) (ii) (a)**

Conductor in Electrostatic Equilibrium 靜電平衡

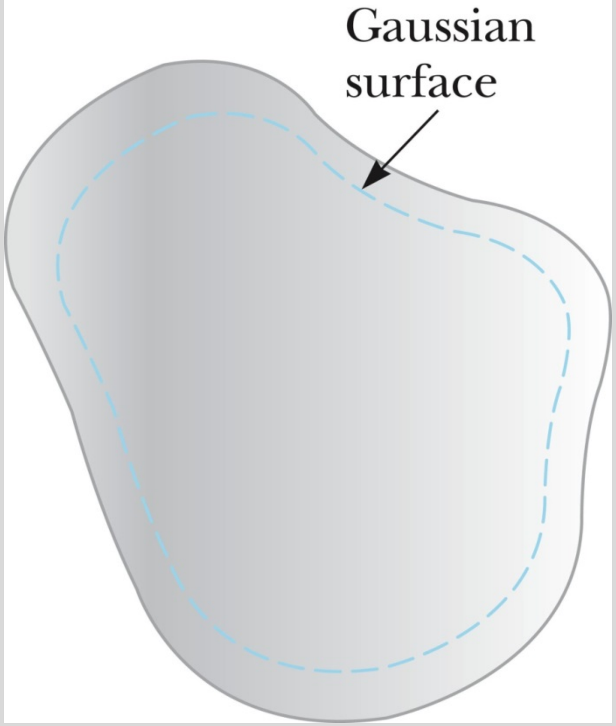
- No net motion of charge within a conductor
  - Property 1: **$E_{inside} = 0$**
    - Whether the conductor is solid or hollow
  - Property 2: **Charge resides on its surface**
  - Property 3: The **electric field** at a point just outside a charged conductor is **perpendicular** to the surface and has a magnitude arround σ/ε_0.
    - σ is the surface charge density at that point.
  - Property 4 : for Irregularly shaped conductor σ is **greatest** where radius of **curvature smallest**

Conductor in Electrostatic Equilibrium

- P1: $E_{inside} = 0$
  - Free electrons in the conductor would experience an electrical force and move if E is not 0



- P2: Charge on the Surface
  - $E_{inside} = 0 \rightarrow \phi_E = 0 \rightarrow Q_{inside} = 0$
  - The gaussian surface can be as close to the actual surface



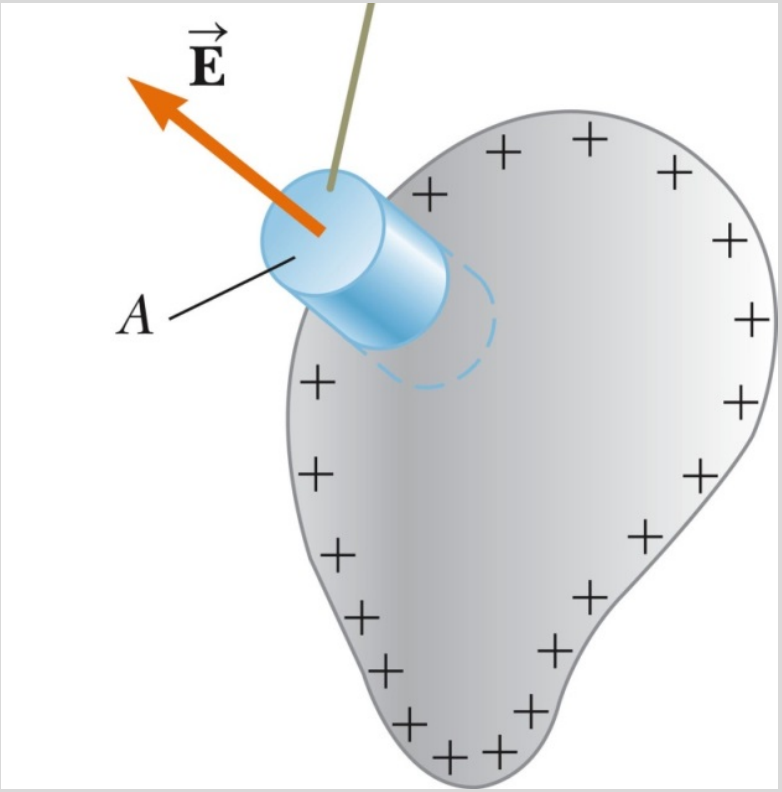
Section 24.4

Conductor in Electrostatic Equilibrium

- P3: Field's Magnitude and Direction
- Choose a cylinder as the gaussian surface
  - Charges would experience a force and move If there were a parallel component

$$\Phi_E = EA = \frac{\sigma A}{\varepsilon_0} \; and \; E = \frac{\sigma}{\varepsilon_0}$$

(Gauss's Law)

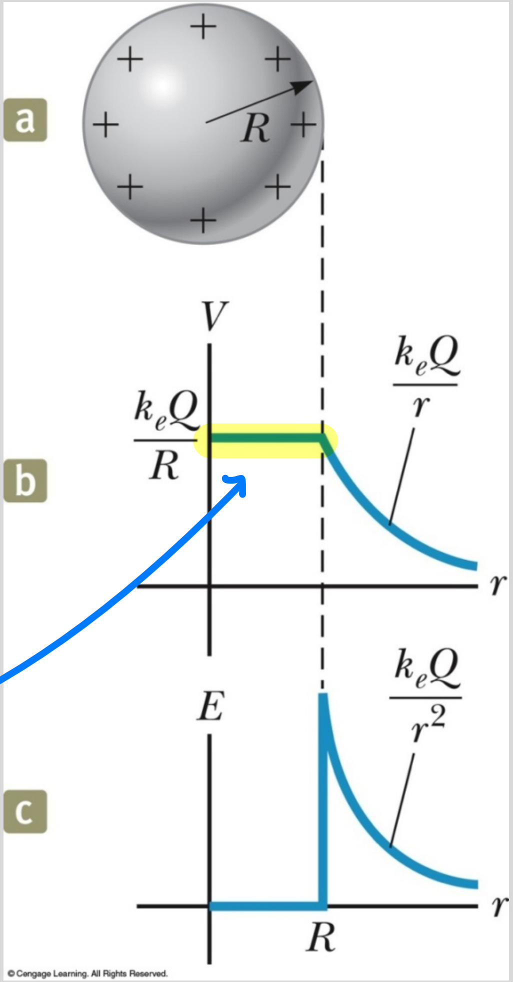


V Due to a Charged Conductor

- The surface of any charged conductor is in electrostatic equilibrium
  - $\vec{\mathbf{E}}$ is always perpendicular to the displacement $d\vec{\mathbf{s}}$
  - $\vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} = 0$, $V_A = V_B$ for any two points on the surface

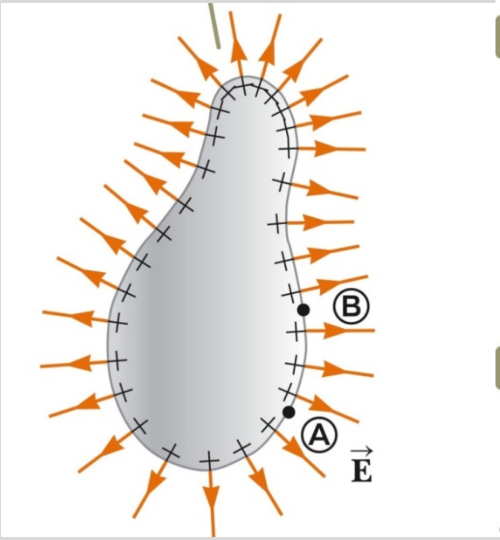
$$\Delta V = -\int_A^B \vec{E}\_in \cdot d\vec{s} = -\int_A^B 0 \cdot d\vec{s} = 0$$

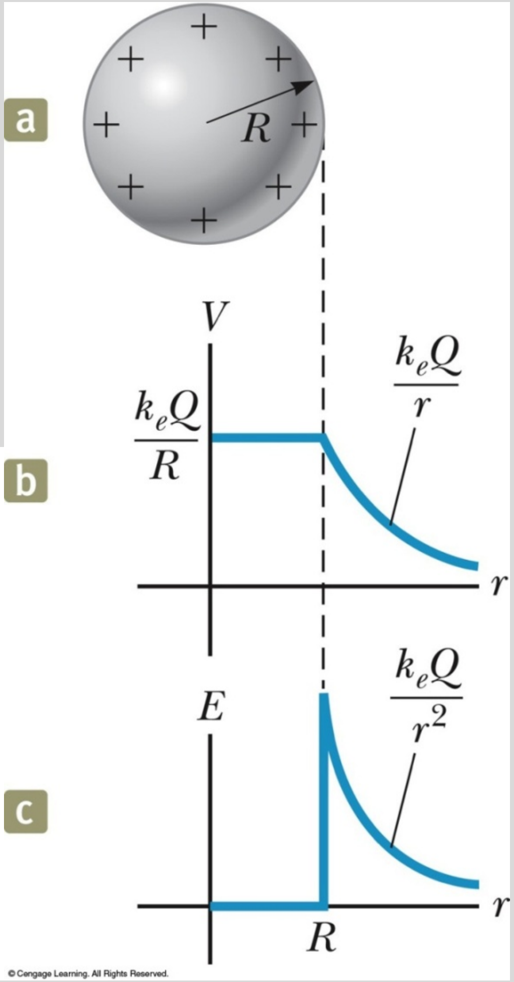
V = constant,
everywhere inside the conductor,
including the surface,
which may or may not be zero,



V Due to a Charged Conductor

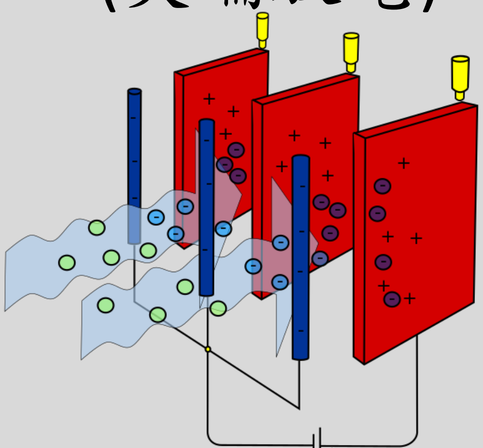
- The surface of any charged conductor is in electrostatic equilibrium
  - $\vec{\mathbf{E}}$ is always perpendicular to the displacement $d\vec{\mathbf{s}}$
  - $\vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} = 0$, $V_A = V_B$ for any two points on the surface
- High charge density near the convex points (small curvature)
  - Strong E → Corona Discharge (尖端放電)
  - The **glow** that results from the **recombination of free electrons with the ionized air molecules**

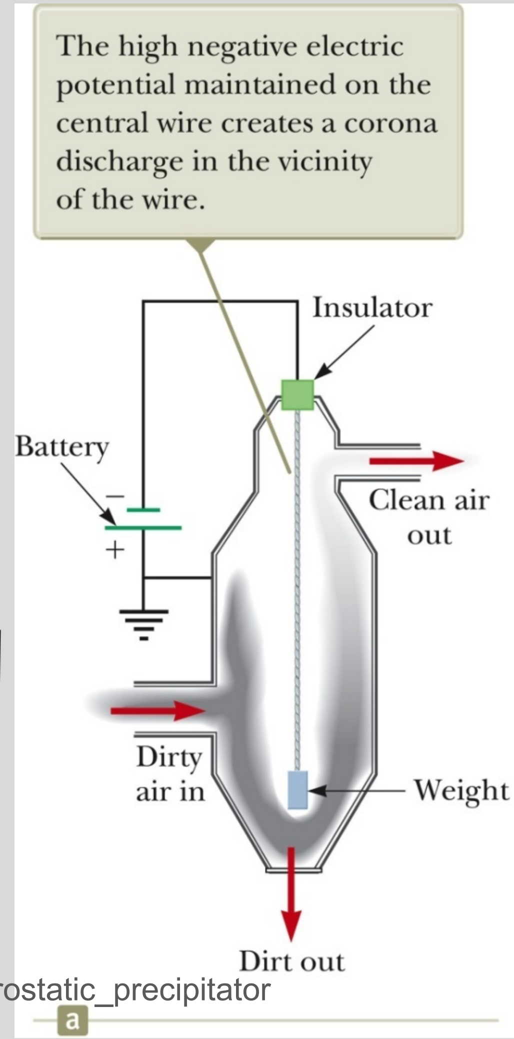




Some note

- Electrostatic Precipitator (靜電除塵) by Corona Discharge (尖端放電)

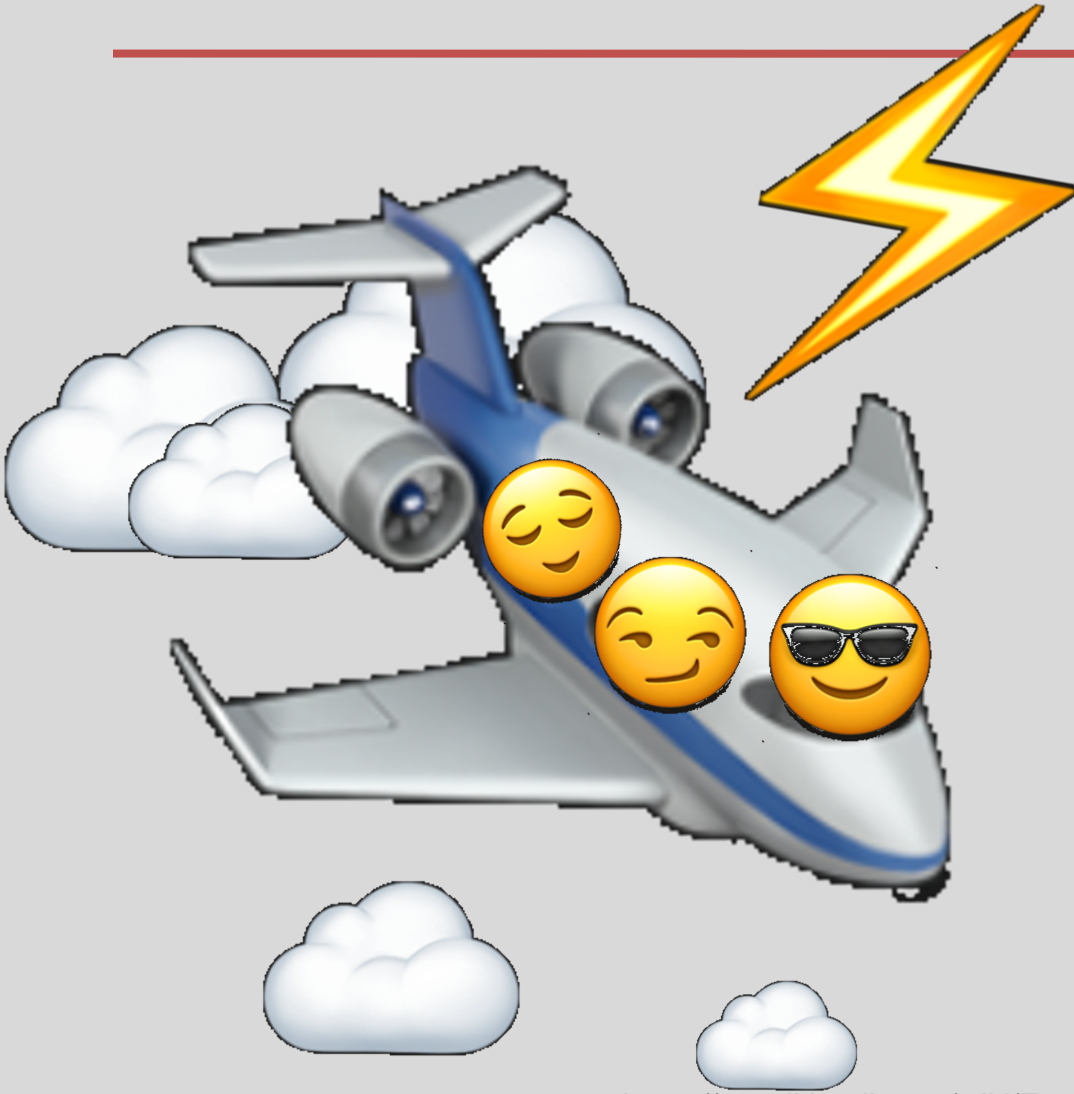


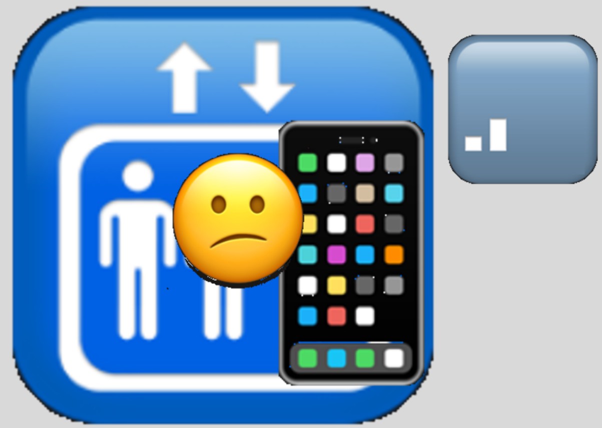


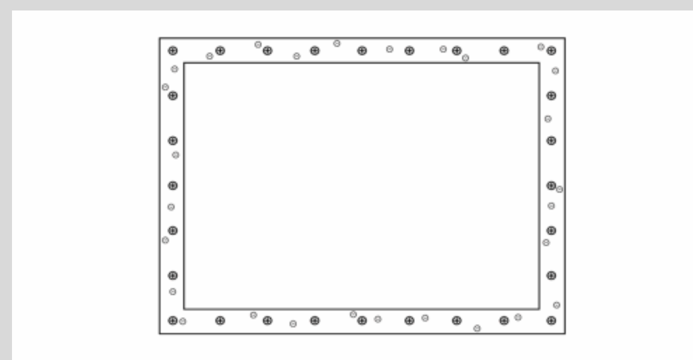
https://en.wikipedia.org/wiki/Electrostatic_precipitator

- Faraday cage

Faraday cage





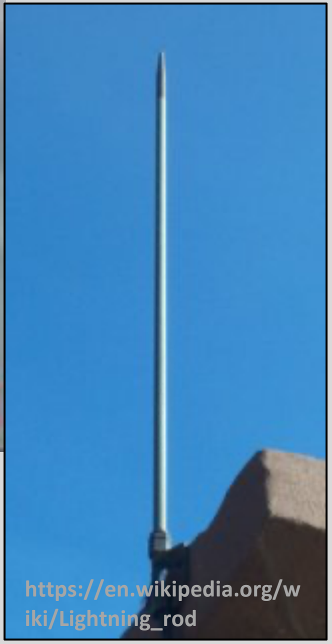


https://en.wikipedia.org/wiki/Faraday_cage

Tesla Coil

https://www.youtube.com/watch?v=n-OToUAelzo
https://en.wikipedia.org/wiki/Corona_discharge
https://en.wikipedia.org/wiki/Tesla_coil

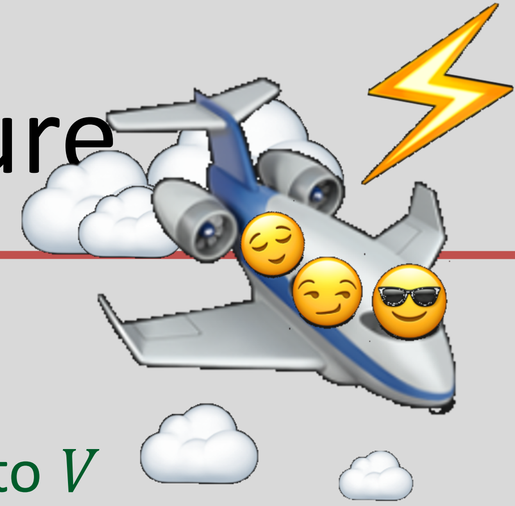
Thor with Lightning on the Tower



The Avengers

https://www.youtube.com/watch?v=ZYWz8MEFEIQ

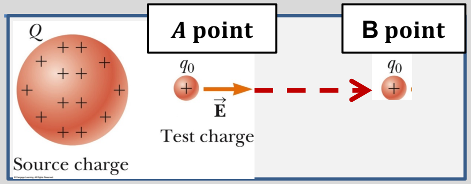
This Lecture



- Electric Potential Energy U

  Electric Potential V (Volt)

From E to V



- Electric Potential Difference ΔV In a Uniform Electric Field E
- Electric Potential V Due to Point Charges

- Find the Electric Field E from the Electric Potential V

  From V to E

  – Uniform Charged Ring
  – Uniform Charged Disk

- Conductors in Electrostatic Equilibrium