GD: Batteries, Capacitors, Circuits
活動單元：電池,電容器,電路組

By A. Assefa, B. Lin, A. Chaudhari, J D White
Applied Electrostatics

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0. Introduction 簡介

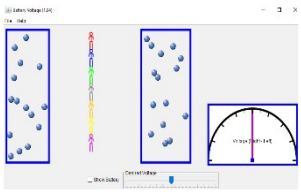
在這個單元，你將用虛擬物理實驗模擬，來展現你學過的靜電的應用。 在開始回答問題之前，請大家先玩線上的模擬實驗。熟悉每一個特性和按鈕，也確定瞭解怎麼用每一個每個工具。玩模擬實驗的時候，可以使用中文和英文兩種界面，大家就可以同時學到中英文關鍵字的對應囉！

In this activity unit, you will perform virtual experiments with public domain physics simulations dealing with applied electrostatics – the practical application of the physics you have been learning. Before you start answering the questions, play with each simulation. Get familiar with each of the different effects and buttons of the animations. Where there are tabs, utilize them. Run the simulations in both Chinese and English so you can be bilingual!

1. Batteries and Voltage

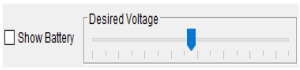
A Download, Run & Play with "Battery and Voltage" 下載「電池、電壓」模擬器

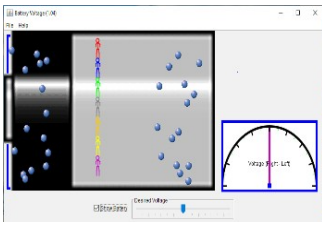
B Observe



1. What do the balls represent in a battery? 球在電池裡代表什麼？

2. When you change the desired voltage, what happens? 改變電壓的時，人發生了什麼事情？

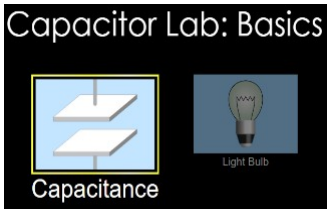




3. These little men represent chemical reactions that separate positive and negative charge creating a potential difference between the two ends of the battery. 畫面裡的人代表分開正負電荷的化學反應，分開的電荷在電池的兩端產生電位差

4. Check box "Show Battery" 點選「顯示電池」Slide the desired voltage to the far right. Then move the slider to the far left. What happens? 把電壓調到最右，再拉回最左邊的過程中，有什麼事情發生?

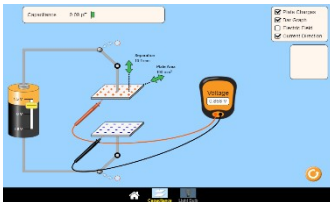
5. The battery has two ends. One with a protrusion and on that is flat. At which end are their more electrons? 電池一端突出、另一端平坦。哪一端有比較多的電子？



2. Capacitors 電容

A Download, Run & Play with "Capacitor Lab: Basics". Initially use the left button: Capacitance 下載「電容實驗室：基礎」模擬器，先用左邊電容按鈕。

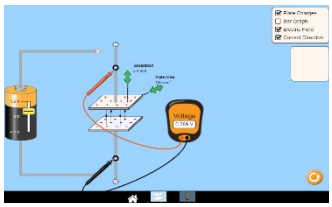
B Observe with the Battery Connected:



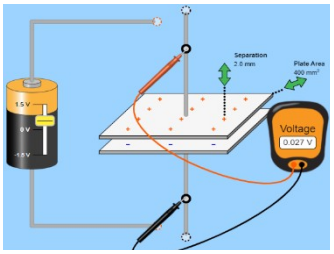
1. Vary the potential on the battery from 0 V to -1.5V to +1.5V. As you vary the voltage, how does the number of negative and positive charges on the plates change? How does the electric field between the plates change? 將勾選在白色框框內的所有複選框 Check all the boxes. 改變電池電壓：0V → -1.5V → 1.5V。當你改變電壓時，正負電荷在平行板上的分佈數量有什麼改變？電場在平行板之間是怎麼變化?

2. Connect the volt meter and measure the voltage between the two capacitor plates. How does it vary with the battery output? 連接伏特計量測電容兩側的平行板電壓。電壓是如何跟著電池輸出改變

C Observe with Battery Disconnected (break the circuit). 斷開電池和電容（形成開路）



1. What happens to the number of charges on the plates, electric field and the voltage between the two plates? 平行板上電荷數量怎麼變化？在平行板間電場怎麼變化？電壓怎麼變化？



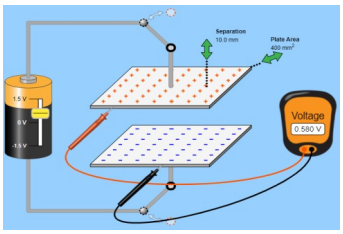
2. Reduce the separation between the two plates, what happens to the number of charges, electric field strength (lines) and the voltage difference between the plates?

   降低平行板的**間距**，電荷的數量怎麼變化？電場怎麼變化？電壓怎麼變化？

3. Increase the size (area) of the parallel plates, what happens to the number of charges, electric field, and the voltage difference between the plates?

   提高平行板的**面積**，電荷的數量怎麼變化？電場怎麼變化？電壓怎麼變化？

D Observe with battery connected (complete the circuit). 重連電池和電容（完整電路）



1. What happens to the number charges on the plate, electric field and the voltage difference between the plates?在平行板上電荷的數量怎麼變化？平行板間電場怎麼變化？電壓怎麼變化？

2. Reduce the separation between the two plates, what happens to the number of charges, electric field strength and the voltage difference between the plates?

   降低平行板的**間距**，電荷的數量怎麼變化？電場怎麼變化？電壓怎麼變化？

3. Increase the size (area) of the parallel plates, what happens to the number of charges, electric field, and the voltage difference between the plates?

   提高平行板的**面積**，電荷的數量怎麼變化？電場怎麼變化？電壓怎麼變化？

E Experiment: Relationship of Voltage with Plate Separation and Area (Constant Charge) 平行板間距、面積對電壓的影響實驗（固定電荷）

1. In order to do the experiment and find a mathematical relationship it is best to first define some parameters:為了做實驗和找出其中的數學關係式，先定義幾個參數
   - Q: Total charge on the plates 平行板上總電荷量
   - A: Area of the plates 平行板面積
   - d: Separation of the plates 平行板間距
   - ΔV: Potential difference between the plates 平行板間電位差
2. For this first experiment, Q will be fixed (so we need to disconnect the battery) 第一個實驗需要固定Q（所以我們需要斷開電池）
3. (a) Vary the separation (d) between the plates and (i) record the potential difference (ΔV). Based on your measurements, (ii) draw a graph and (iii) write an equation relating ΔV and d (right side of table) Note the area of the plates you use in this calculation and keep it constant. (Use a spreadsheet such as Excel or calc) 改變平行板的間距，記錄電位差(ΔV)。依據你的實驗結果畫出關係圖(一個當 X 軸、一個當 Y 軸)、寫下電位差 ΔV 和間距關係式。注意：平行板面積的計算。

(i) Plate area (mm^2)		**(ii) Graph ΔV(d)**	**(iii) Equation ΔV(Q=const, d, A=const) =**
Separation d [mm]	**ΔV [V]**		

4. Vary the area of the two parallel plates and record the potential difference (ΔV). Based on your measurements, (b) graph and write an (c) equation relating ΔV and the area of a capacitor (right side of table). Note the separation of the plates used for this work. 改變平行板面積的大小並記錄電壓的變化。依據你的量測結果，畫出關係圖(一個當 X 軸、一個當 Y 軸)、寫下電容電位差和面積的關係式。注意：固定平行板間距。

(i) Plate separation (d) [mm]:		**(ii) Graph ΔV(A)**	**(iii) Equation: ΔV(Q=const,d=const,A) =**
Area [mm2]	**ΔV [V]**		

5. Vary the output of the battery. Can you guess about how ΔV varies with the amount of Q on the two plates? I.e, ΔV(Q, d=constant, A=constant)=?? Try to write it as an equation with a constant to be discovered. 改變電池輸出。估算電位差如何隨Q在平行板上的量改變的量？請寫下兩者關係式 ΔV(Q)=？設 d 和 A 都是固定值。

6. Combine the equations in questions 1 to 3, to get a single equation relating the Potential Difference ΔV , separation (d) and area of the plates (A) for a given charge Q, I.e, V(Q,d,A)= 結合 1 到 3 的關係式成為使用電位差（V）、平行板間距（d）、平行板面積（A）的關係式 V(Q,d,A)=？

7. To make calculations simpler, one defines a quantity called Capacitance with units of picoFarads (pF) that takes into the geometry only of the system (i.e. d and A and the material used in the capacitor ε). By defining this quantity (Capacitance), we can then write equation relating the voltage and charge, hat does not specifically mention d and A, 為了讓計算變得比較簡單，定義電容量 C 的單位為皮法（picoFarads, pF），其包含系統結構參數 d、A 和 ε。然後，我們可以透過電壓、電荷量來定義電容量，而不需要用系統結構參數 d 和 A。關係式如下：i.e.:

$$\Delta V = Q\frac{d}{\epsilon\epsilon_0 A} = \frac{Q}{C} \quad where \quad C = \frac{\epsilon\epsilon_o A}{d} \quad (1)$$

F 挑戰 Challenge

1. The maximum emf that is generated by the battery is 1.5V. What is the maximum potential difference that one can obtain between the two parallel plates? (Hint it is not 1.5V)

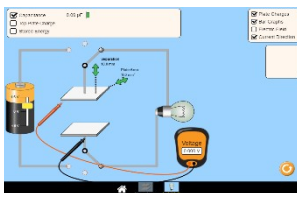
   電池產的最大電動勢為 1.5V。請問平行板最大的電位差為？（提示：不是 1.5V）

2. Explain how you can maximize the potential difference between the two parallel plates with a step by step algorithm. 請解釋怎麼能夠最大化平行板間的電位差？請列出步驟。

3. What is the relationship between Capacitance and the potential difference for a given charge Q. Circle a,b,c? 固定 Q 電荷量的情況下，請問電容量和電位差的關係為 a, b, c 哪一個？
   a. Smaller the capacitance, the greater the potential difference ΔV for a given charge Q. 在固定 Q 電荷量的情況下，增加電位差 ΔV ，則電容量變小。
   b. Larger the capacitance, the greater the potential difference ΔV for a given charge Q. 在固定 Q 電荷量的情況下，增加電位差 ΔV ，則電容量提大。
   c. No relation. 兩者沒有關係

G 觀察 Observe a Light Bulb (Click on the right button: Light Bulb.勾選右邊的按鈕：燈泡)

1. a. Use the battery to put charge (Q) onto the capacitor. b. disconnect the battery. c. connect the capacitor to the light bulb. What happens? 用電池推動 Q 到電容，然後斷開電池後，再將電容連接到燈泡。發生了什麼事？



2. Observe carefully. After you connect the circuit how does the intensity of light varies with time?觀察將電容和燈泡連接之後，燈泡強度是怎麼隨時間變化的？

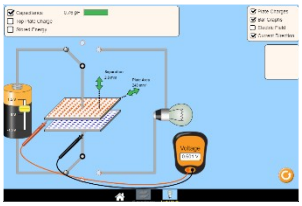
H Experiment: Relationship between the time Light emitted and Capacitance 發光時間與電容量變化關係實驗

1. Vary the capacitance (C) and (i) record the length of time the light (τ) remains on. (ii) Graph & (iii) Write an equation relating the length of time light is emitted and the device capacitance. 改變電容量 C，並記錄發光時間長度 τ 。然後再右邊，根據數據畫出關係圖(一個當 X 軸、一個當 Y 軸)，寫下發光時間長度和電容量的關係式。

C [pF]	(i) Time [s]	(ii) Graph t(C)=	(iii) Equation

2. We have seen that capacitance determines the time light is emitted. Lets see what affect potential difference(ΔV), charge(Q) has. (Note if ΔV is set, and C is a constant then Q is also determined). Change the ΔV/Q on the parallel plates keeping the Capacitance (C) constant. What affect does this ave on the light emitted? 我們已經看到了電容決定了發光長度，讓我們來看看 ΔV 的影響為何? 改變平行板上 ΔV/Q 使電容量(C)為定值。

3. The amount of light emitted from the light bulb as a function of time can be written using the following equation:



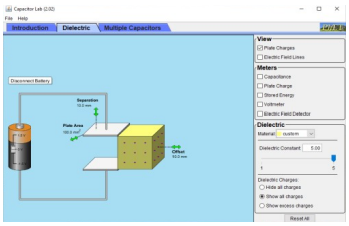
$$I = k\,Q\ \exp\left(\frac{-t}{RC}\right) \quad (2)$$

The R in the denominator is the internal resistance of the light bulb and k is a constant.

3. Real Capacitors

A Download, Run & Play with "Capacitor Lab". Use the Dielectric Tab.

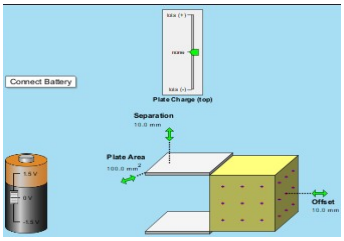
B Observe:



1. Turn on the meters. With the battery connected, record the Capacitance (C), Stored charges (Q), Stored Energy (E), at two different plate separations (d). For all the following questions, use d=5mm as the common case. 在上方的標籤點選介電質，改變兩平行電擊板之間的距離，請問平行電擊板間的距離與所儲存的電荷量有什麼關係?

d	C [pF]	Q [pC]	E [pJ]	ΔV [V]	
5					

2. What changes occurred as the plate separation and hence capacitance changed (ΔV=constant)? 總結在電位差下電容值減少，發生甚麼變化?



3. Disconnect the battery. Record the Capacitance (C), Stored charges (Q), Stored Energy (E), at the same two plate separations (d). 在上方的標籤請點選介電質，不改變兩平行電擊板之間的距離，請問平行電擊板間的距離與所儲存的電荷量有什麼關係?

d	C [pF]	Q [pC]	E [pJ]	ΔV [V]	
5					

4. What changes occurred as capacitance decreases at constant charge (Q)? 總結在恆定電荷下、電容值減少，發生甚麼變化?

5. Every material is characterized by its unique dielectric properties by the parameter ε. (relative dielectric constant) For air this parameter is ~1. (all our previous experiments are done in air) Leaving the battery disconnected, place different materials between the two parallel plates and record he effect on the observables. 每個材料有不同的特徵在於材料個別獨有的介電特性。我們之前的實驗都在空氣中完成、數值約=1，現在，不要連接電池，將不同材料放在兩平行板間並記錄影響了什麼?

ε	d (constant)	C [pF]	Q [pC]	E [pJ]	ΔV [V]
1					

ε	d (constant)	C [pF]	Q [pC]	E [pJ]	ΔV [V]

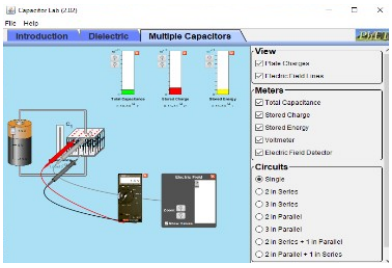
6. What changes occurred when relative dielectric constant increases? 總結當相對介電常數增加，會發生什麼變化。

7. Connect the battery. Place different materials between the two parallel plates and record the effect on the observables. 連接上電池，將不同材料放在兩平行板間並記錄影響了什麼?

ε	d (constant)	C [pF]	Q [pC]	E [pJ]	ΔV [V]
1					

8. What changes occurred when relative dielectric constant increases? 總結當相對介電常數增加，會發生什麼變化。

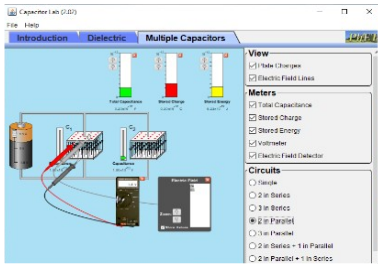
9. All these effects are included in a single equation: 這些現象可以以一個簡單的方程式表達:



$$C = \frac{\epsilon \epsilon_0 A}{d} \quad (3)$$

where A is area of the capacitor, d the separation of plates and $\varepsilon\varepsilon_o$ describes the material contained within the capacitor. Knowing C we can then relate the potential difference (ΔV)and charge (Q) stored in a capacitor with a simple equation: 知道了 C 後，我們就可以將存儲在電容器中的電位差 ΔV 和電荷以一個簡單的等式寫出來： $Q = C\Delta V$ (4)

C Application to Circuits: Capacitors in Series and Parallel



1. All the geometrical information can be included in C so that just eq. 4 can be used to relate ΔV and Q once we have the total capacitance (C_{Tot}). Change to the Multiple Capacitors Tab. Get familiar with the meters and functions. 切換到“多重電容器”選項，熟悉儀表和功能。
2. Set the capacitance of the single capacitor to 1.0e-13 F and set the emf of the battery to 1.5 V. 將單個電容的電容值設置為 1.0e-13 F，並將電池的電動勢設置為 1.5 V. Record the stored energy (E_{tot}) and total charge (Q_{tot}) (below)

Total	1 Capacitor	(Q3) 2 Capacitors	(Q3) Change	(Q4) Equation
ΔV [V]	1.5			
E_{tot} [J]				
C_{tot} [pF]	0.1			
Q_{tot} [nC]				

3. Add a second capacitor in **parallel.** Explain what happens to C_{tot}, Q_{tot} , E_{tot} and ΔV across each capacitor. 並聯加入第二個電容，說明總電容值、儲存電荷、儲存能量與電壓和原本的差異為何? (above)
4. Based on your observations, write an equation that allows you to calculate the total capacitance (C_T) of the capacitors in parallel if I know C_1 and C_2 and... 根據你的觀察，寫下在並聯中電容(C_T)關係式，假設已知 C_1 和 C_2 和 。(above)

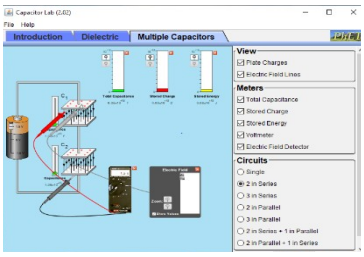
5. Test your equation. Experiment with 3 capacitors in parallel and with capacitors of different values. Does your equation fit the experimental results? 運用三個不同的電容在並聯中值測試你假設的關係式，試試看是否符合結果?

Experiment Configuration			Total Capacitance [pF] (experiment)	Total Capacitance [pF] (Calculated)
C1 [pF]	C2 [pF]	C3 [pF]		

6. Place 2 capacitors in **series**. Explain what happens to C_{tot}, Q, E_{tot} and ΔV across each capacitor. 串聯加入第二個電容，說明總電容值、儲存電荷、儲存能量與電壓和原本的差異為何?

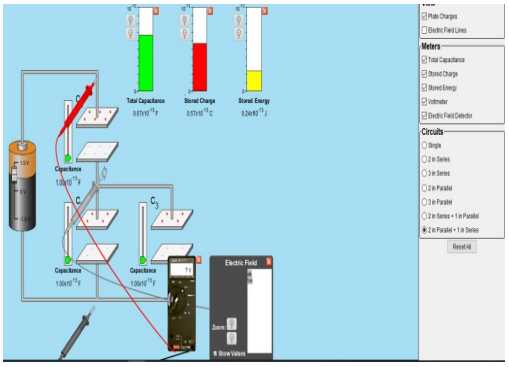
Total	One Cap	Two Caps	Change (Question 6)	Equation (question 7)
ΔV [V]	1.5			
E_{tot} [J]				
C_{tot} [pF]	0.1			
Q_{tot} [nC]				

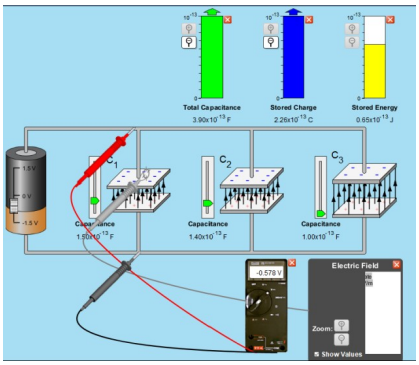
7. Based on your observation, write an equation that allows you to calculate the total capacitance (C_T) of the capacitors in series if I know C_1 and C_2.and C_2 … 根據你的觀察，寫下在串聯中電容(C_T)關係式，假設已知 C_1 和 C_2 和。(above)

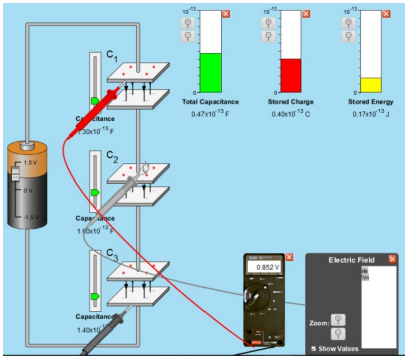


8. Test your equation. Experiment with 3 capacitors in series with capacitances of different values. Does your equation fit the experimental results? 運用三個不同的值測試你假設的關係式。

Experiment Configuration			Total Capacitance [pF] (experiment)	Total Capacitance [pF] (Calculated)
C1 [pF]	C2 [pF]	C3 [pF]		







D Challenge

1. Write an equation to calculate the Total Capacitance of two capacitors in series and 1 in parallel.

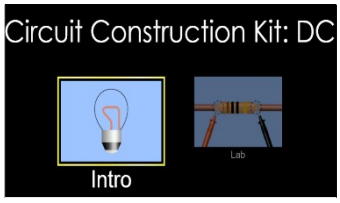
   寫一個方程來計算兩個串聯電容和 1 個並聯電容的總電容。

2. Do the experiment and confirm if the experimental results match your calculations.做個實驗驗證你的計算。

Experiment Configuration			Total Capacitance (experiment)	Total Capacitance (Calculated)
C1	C2	C3		

3. How do we store energy in a capacitor? Draw the diagram of how to do it. In which areas/devices can we use capacitors? 我們如何將電能儲存在電容中？ 繪圖解釋。 我們可以在哪些地方/設備中使用電容器？(Hint: Search why Tesla bought Maxwell)

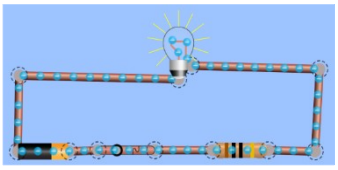
4. Direct Current Circuits 電路組裝套件(直流電)



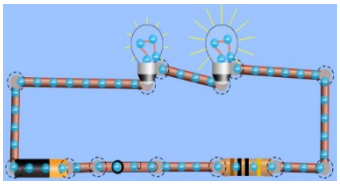
A Download, Run & Play with "Circuit Construction Kit–DC" 下載，運行模擬:電路構造套件-DC

B Observe 3 Simple Circuits with a battery and resistors

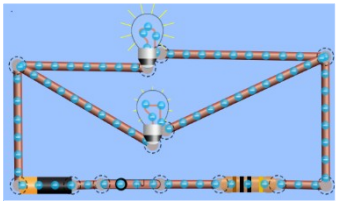
1. Create a full circuit with a battery and a single light bulb. Observe the speed of the electron flow and light emitted. What do you see? 利用電線、電池、燈泡和多個電阻做出一個完整電路，觀察帶電粒子移動的速率，接下來拿掉電阻，寫下你所觀察到的現象?



2. Add a second light bulb to the circuit in **series** with the first light bulb. What happens? Observe the electron speed and the amount of light emitted. Compare with the single light bulb case. 加入第二個燈泡與第一個燈泡**串聯**發生什麼事？ 觀察電子速度和發出的光量，與單燈泡相比。

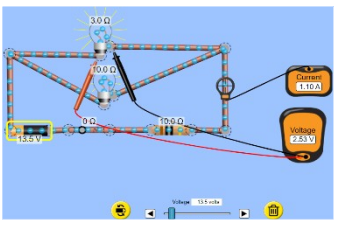


3. Add a second light bulb to the circuit in **parallel** with the first light bulb. What happens? Observe the electron speed and the amount of light emitted. Compare with the single light bulb case. 加入第二個燈泡與第一個燈泡**並聯**發生什麼事？ 觀察電子速度和發出的光量，與單燈泡相比。



C Measure:

1. Turn on the labels. Use the meters to measure current (I) and potential (ΔV). Draw schematics of the three circuits. On the schematics write down the amount of current flowing through each wire and the potential drops across each component of the circuit. 打開標籤並使用各種儀器測量電流和電壓。繪製三個電路的事意圖。在示意圖上寫下流過每根導線的電流量以及電路各組件的電壓降。



Single Light Bulb	2 Light Bulbs in Series	2 Light Bulbs in Parallel

2. Making use of the data from your measurements of the first circuit, write an equation relating the current flowing through the light bulb and potential drop across in the light bulb? 利用測量數據，寫出一個關於流過燈泡的電流和電壓降的方程式？

3. Turn on the Values box. The constant that relates I and ΔV is known as the resistance (R) of that circuit element. Note that the each light bulb has a symbol 10.0 Ω (ohms) This is a measure of how much the light bulb resists (R) the flow of current.打開數值箱。 與 I 和 ΔV 相關的常數被稱為電阻（R）。 每個燈泡標示 10.0Ω（歐姆）是指每個燈泡阻抗多少流過電流的意思。

4. Consider the 2 light bulbs in **series**. Write an equation relating the current flowing out of the battery ($I_{battery}$), and the emf (voltage) V of the battery. What is the value of the constant that connects ($I_{battery}$), and the emf (voltage) V of the battery? How does this constant (R_T) relate to the resistances (R_i) of the light bulbs? 考慮兩個串聯燈泡，寫下流出電池的電流($I_{battery}$)、電池電動勢(ΔV) 為何?寫下與燈泡電阻(R_i)有關的電阻表示法(R_T)，

5. Consider the case of two light bulbs in **parallel**. Write an equation relating the current flowing out of the battery ($I_{battery}$), and the emf (voltage) V of the battery. What is the value of the constant that connects ($I_{battery}$), and the emf (voltage) V of the battery? How does this constant (R_T) relate to the resistances (R_i) of the individual light bulbs? 考慮兩個並聯燈泡，寫下流出電池的電流($I_{battery}$)、電池電動勢(V) 為何?寫下與燈泡電阻(R_i)有關的電阻表示法(R_T)，

5. 您的意見 Student Comments

1. Did you enjoy the activity? 你喜歡這個活動馬？
   □ LOVED 喜爱 □ 75% □ 馬馬虎虎 □ 25% □ HATED 憎恨

Why? 為什麼？

2. 提出 1 或 2 個問題 可以 添加到本題目簿 如果你的問題被使用，加 1 分（最多加分）Suggest additional questions to ask concerning any of these simulations. (If we use your question, you get 1% bonus marks for the course!)

Activity	Suggested Question	Answer to suggested question

3. 有沒有別的意見？ Any other suggestions to improve this activity?
