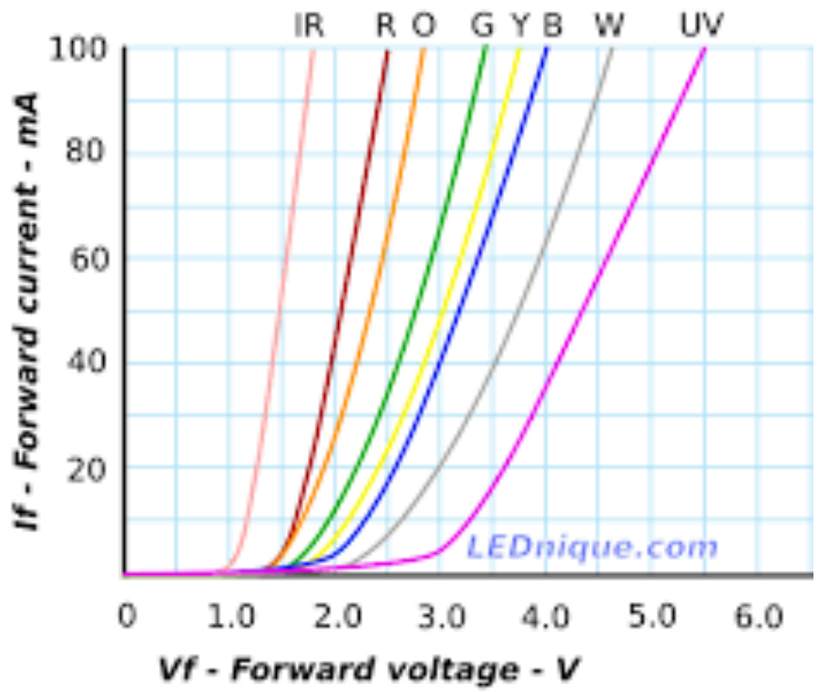
發光二極體中的普朗克常數

高二四 王宏聿

實驗目標

- 測量不同顏色LED的I-V特徵曲線
- 找閥值電壓 V_{th}
- 計算普朗克常數



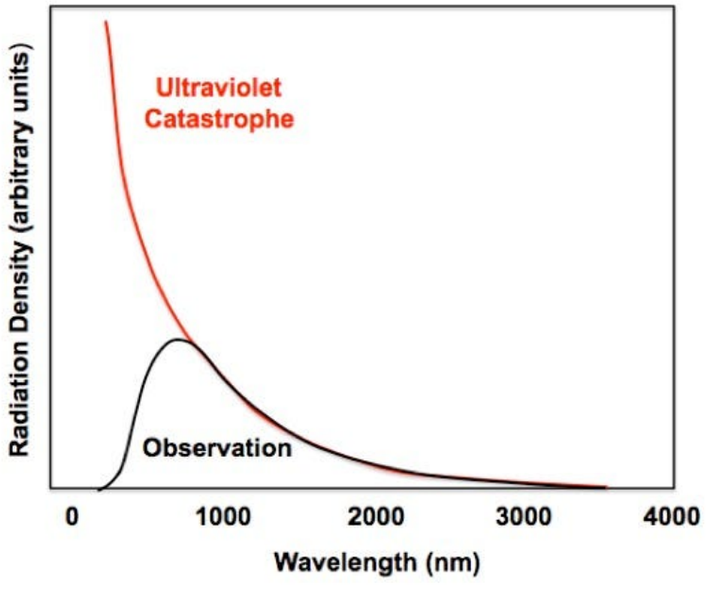
普朗克常數

- $\mathrm{h} \approx 6.626 \times 10^{-34}$
- Planck's equation: $E = hf$

E：光子能量

f：光的頻率

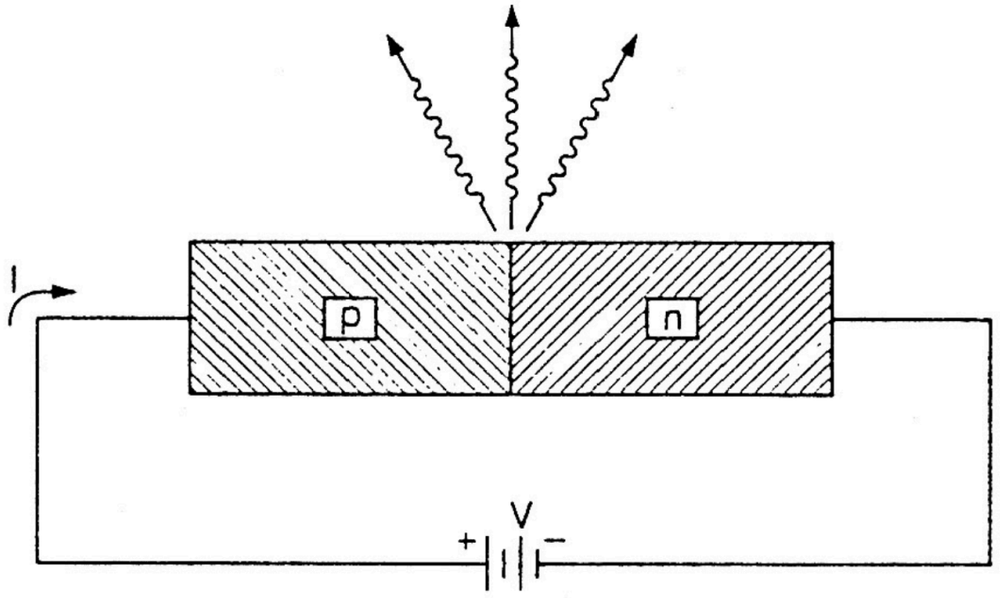
h：普朗克常數



Max Planck
(1858-1947)

Light Emitting Diodes

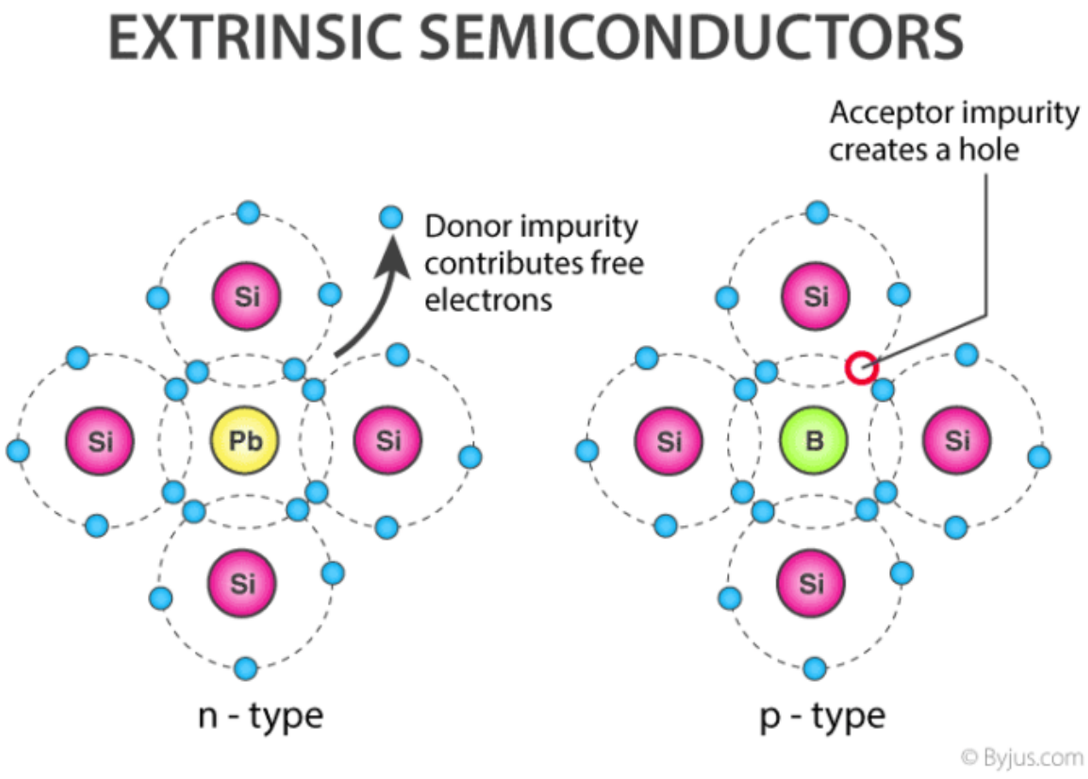
- 電致發光的半導體元件
- P-N 接面：電子與電洞複合，釋放光子



The Benefits of LEDs

- Long lifetime/reduced maintenance costs
- Energy efficiency
- Design flexibility
- Saturated colors
- Directional light
- Robustness
- Dynamic color control
- No strike time—immediate ignition
- No mercury
- Small size
- Low-voltage DC operation

P-type and N-type Semiconductor



n型半導體：

摻入少量五價元素雜質(施主雜質)

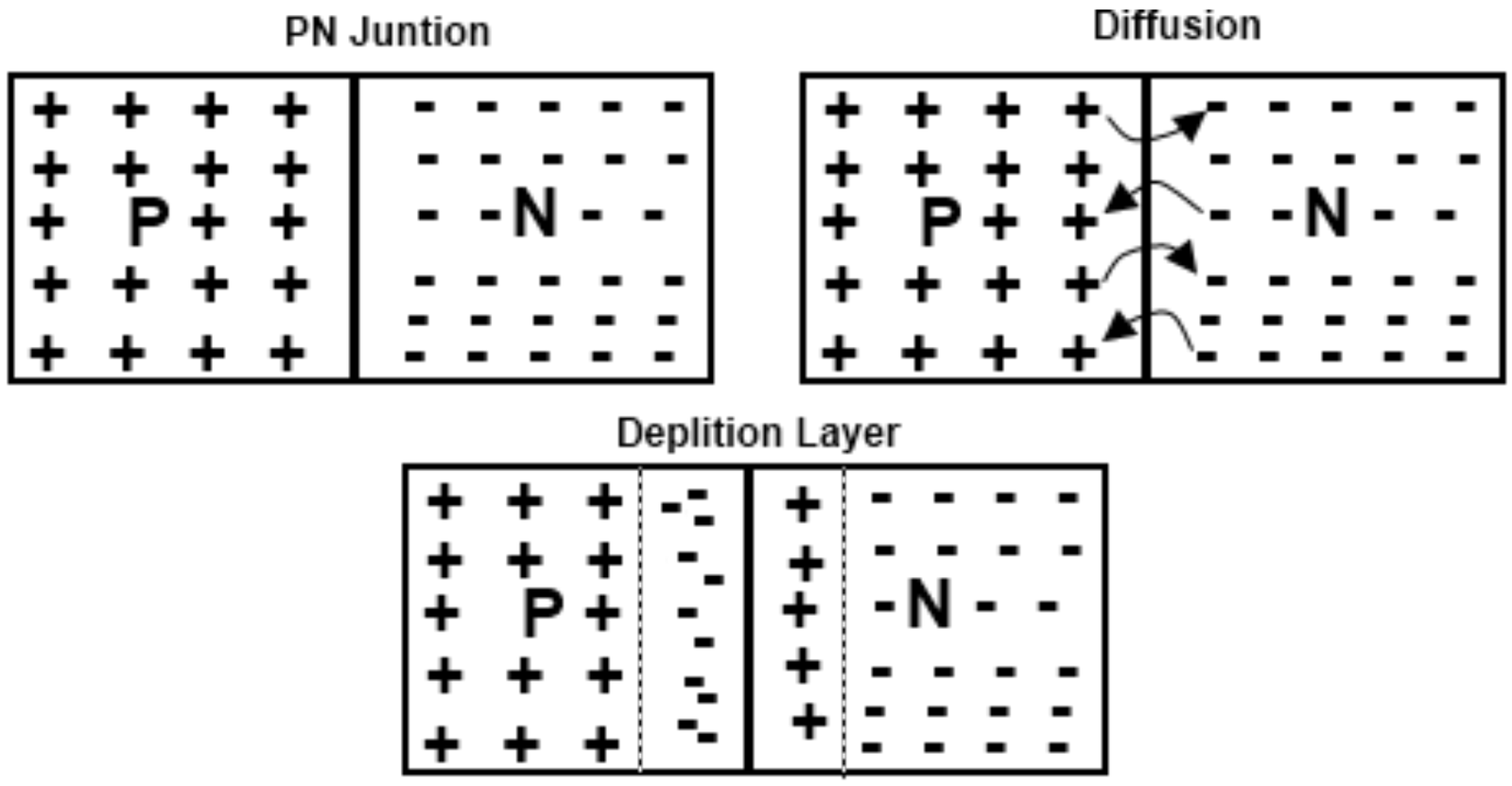
多數載子為電子

p型半導體

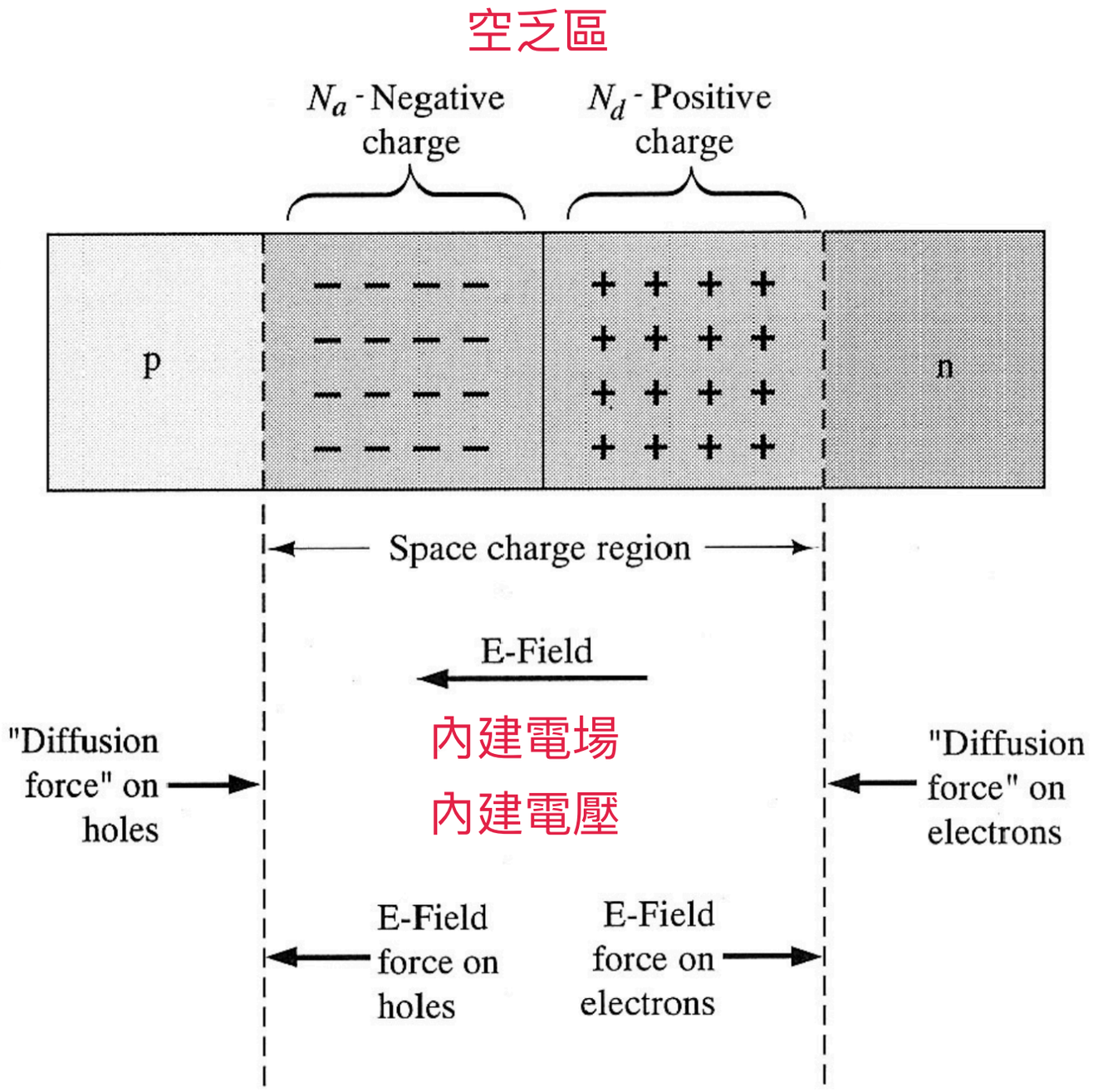
摻入少量三價元素雜質(受主雜質)

多數載子為電洞

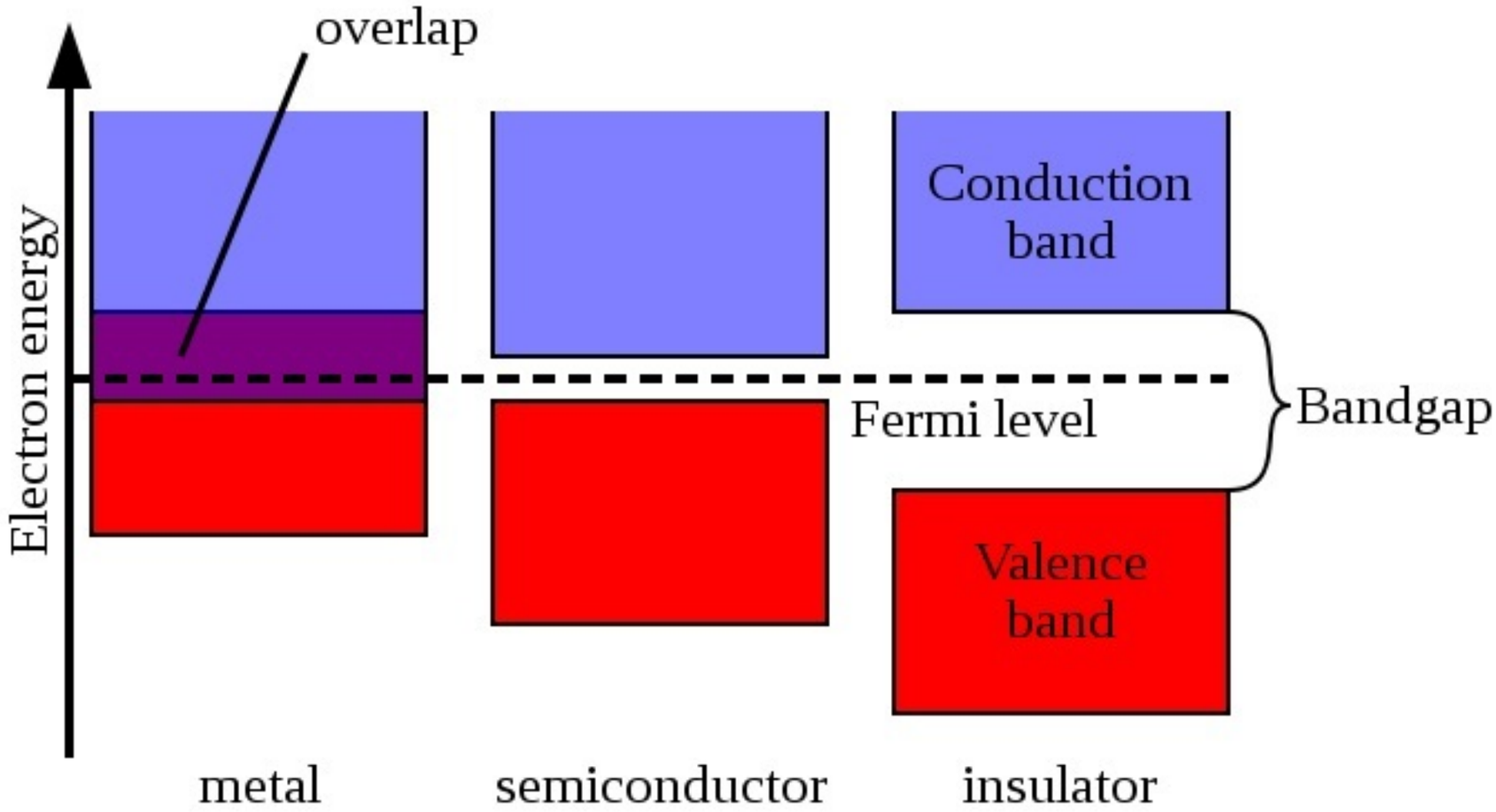
P-N Junctions



P-N Junctions



Valence Band (價帶) and Conduction Band (導帶)

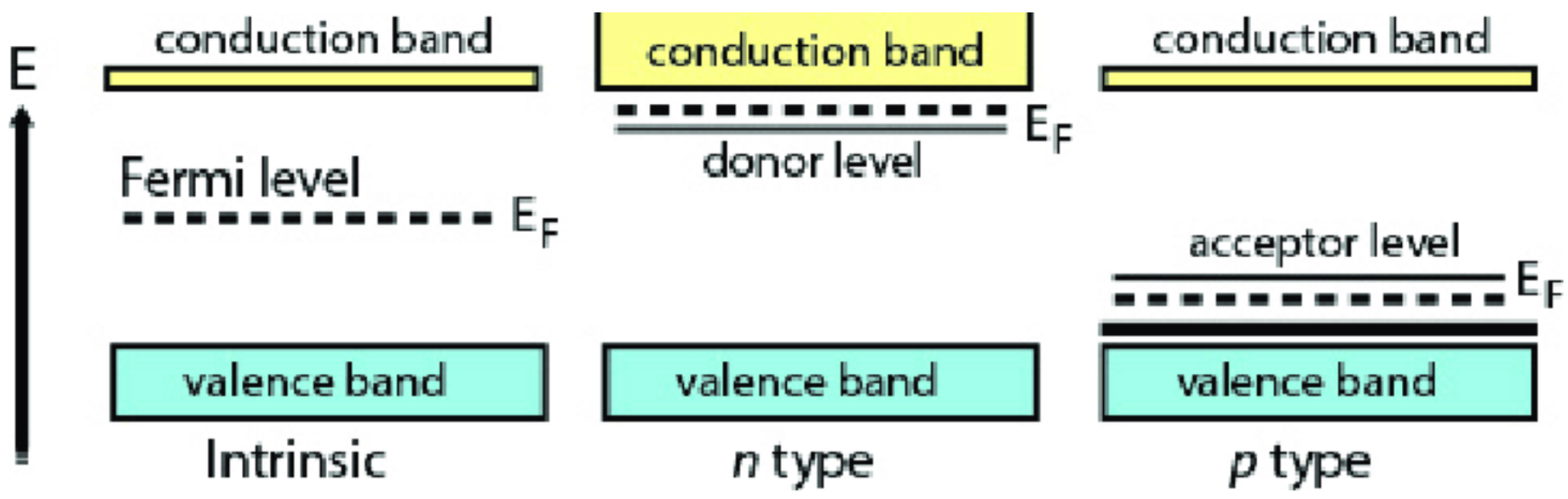


***Fermi level 費米能階**

電子有50%機率佔據的假想能階

Valence Band (價帶) and Conduction Band (導帶)

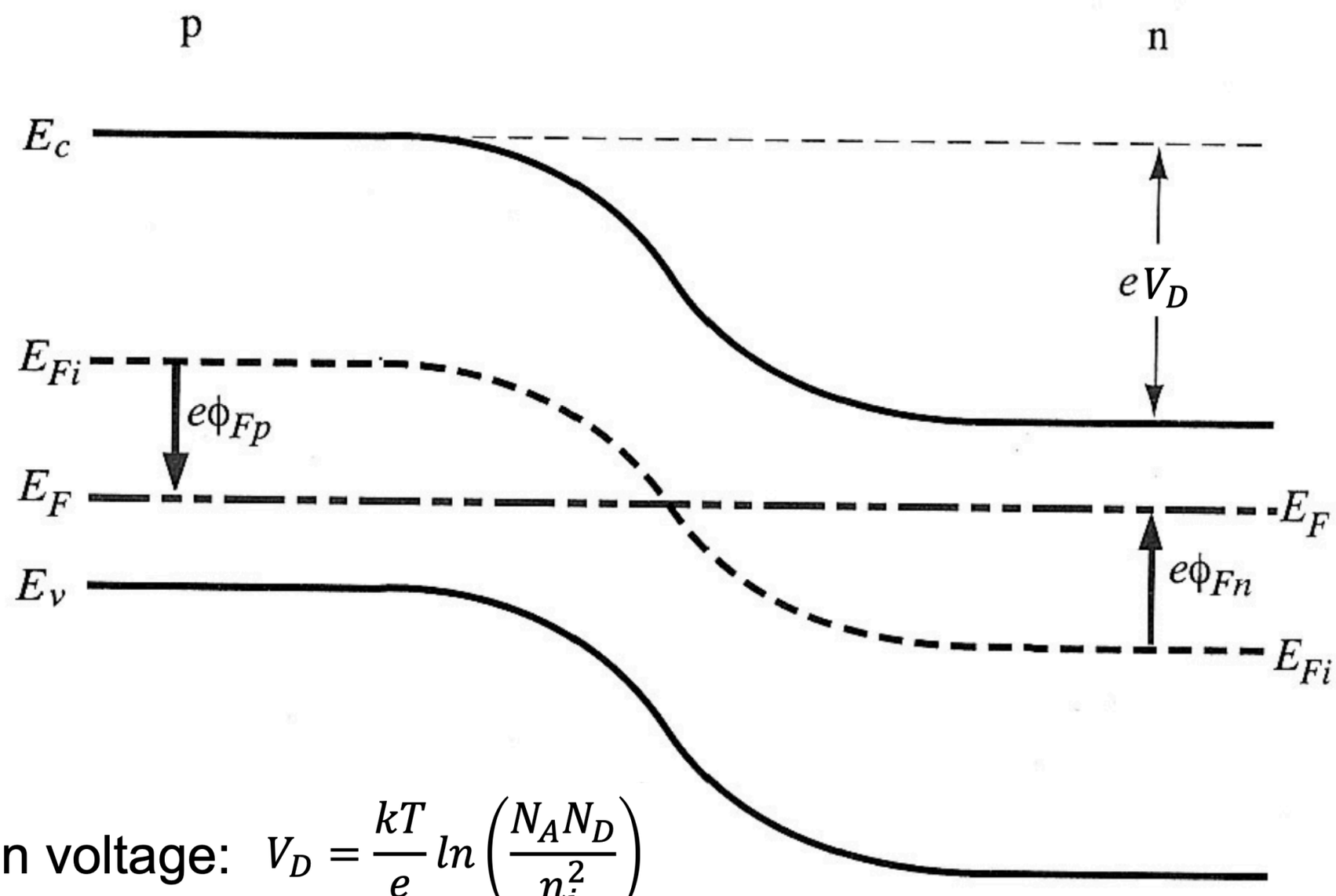
半導體摻入雜質後，費米能階移動：



***Fermi level 費米能階**

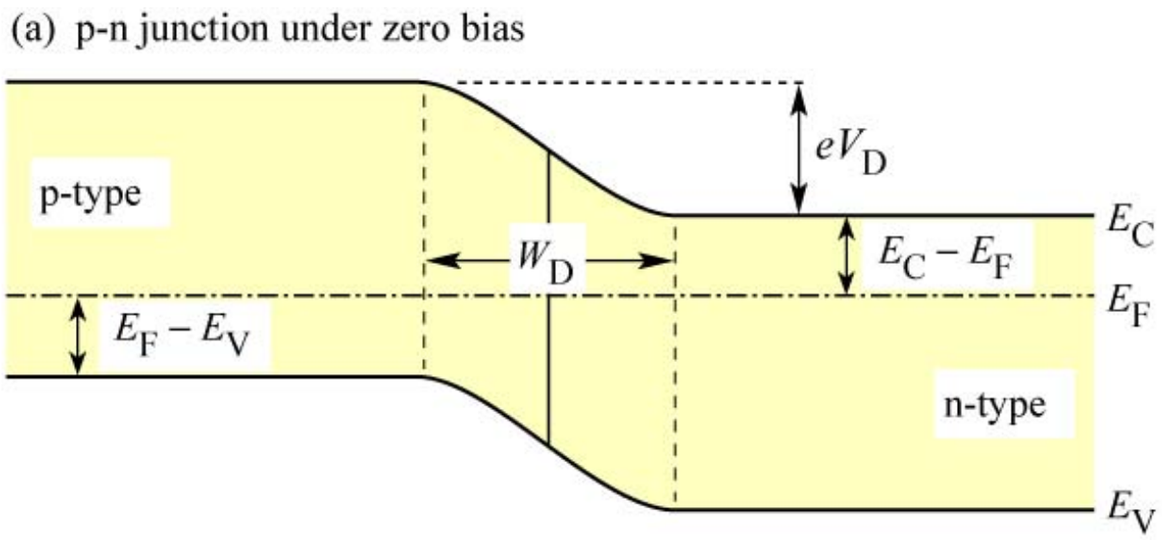
電子有50%機率佔據的假想能階

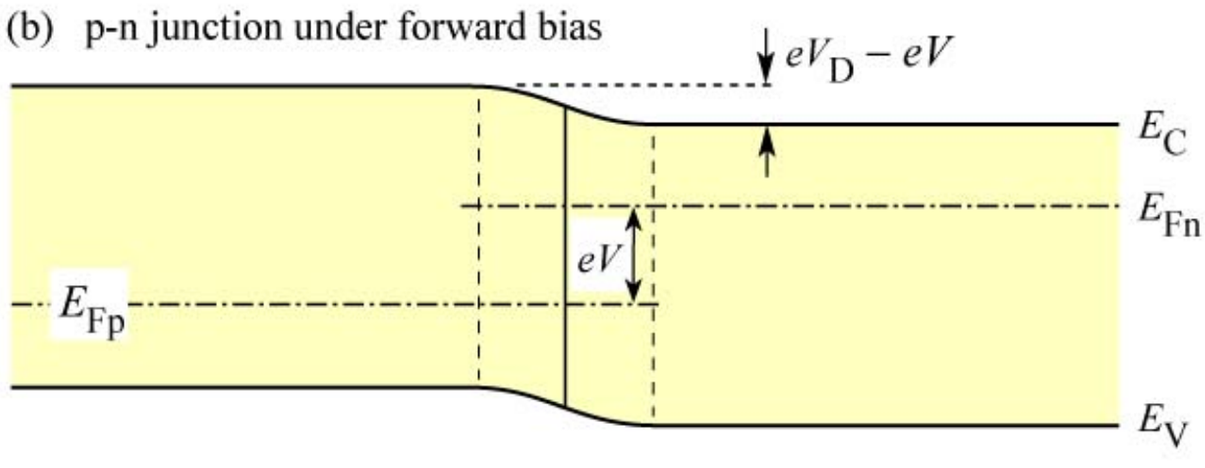
P-N Junctions



The diffusion voltage: $V_D = \frac{kT}{e} ln\left(\frac{N_A N_D}{n_i^2}\right)$

P-N Junctions





The diffusion voltage: $V_D = \frac{kT}{e} ln\left(\frac{N_A N_D}{n_i^2}\right)$

The depletion layer width: $W_D = \sqrt{\frac{2\varepsilon}{e}(V - V_D)\left(\frac{1}{N_A} + \frac{1}{N_D}\right)}$

P-N Junctions

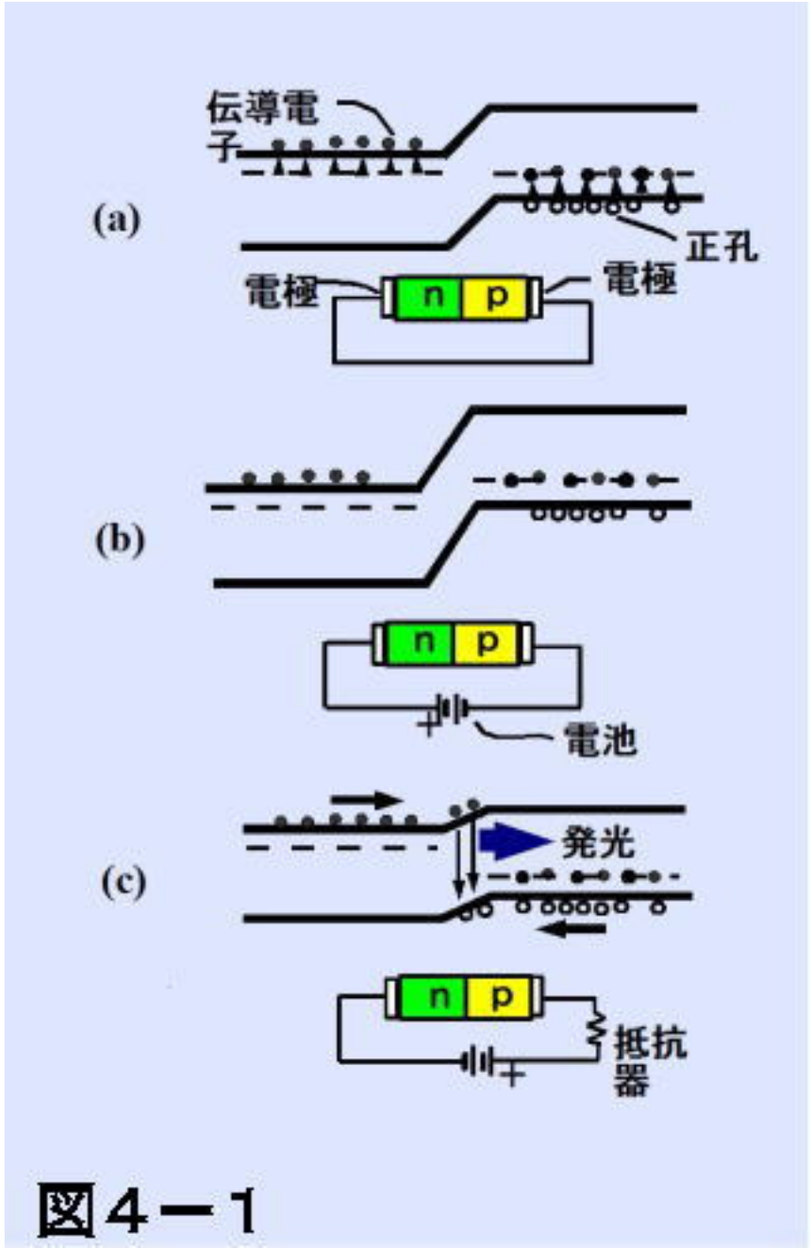
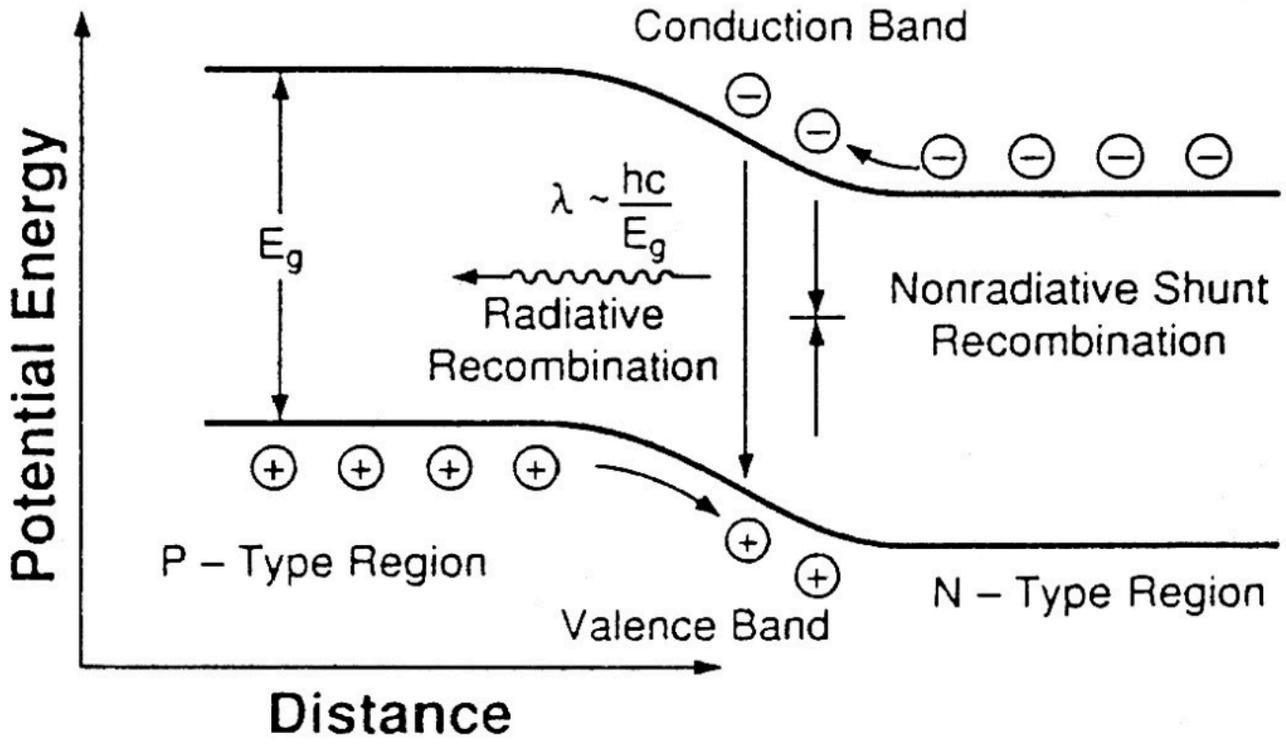


図4－1



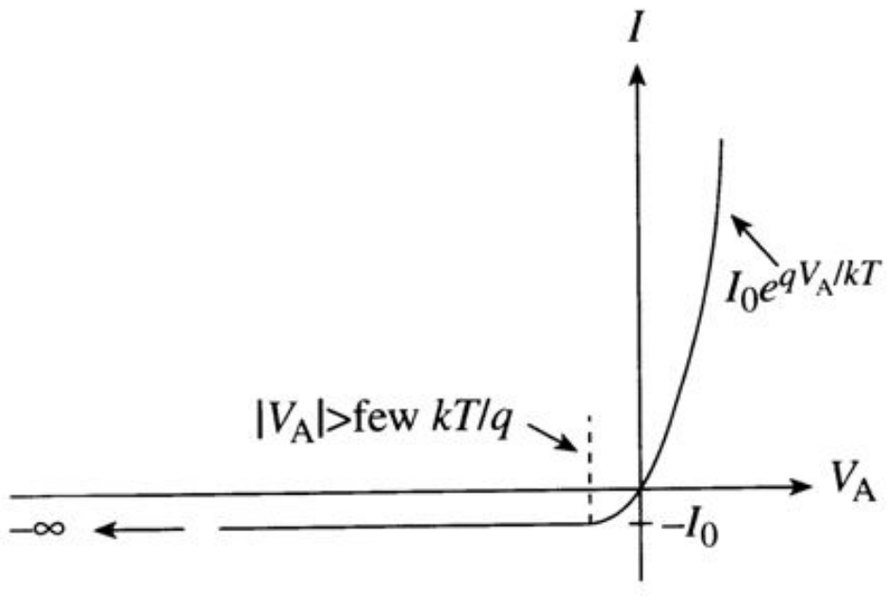
LED所放出的光子能量：E_g

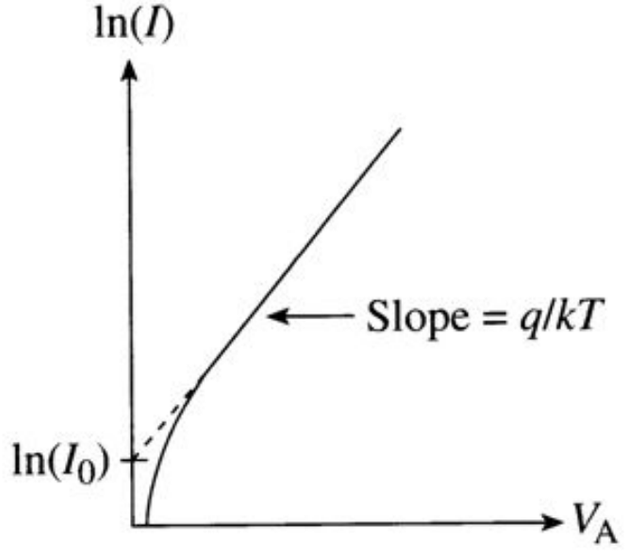
$$E_g = hf_{LED} = \frac{hc}{\lambda_{LED}}$$

Ideal Diode I-V Characteristic

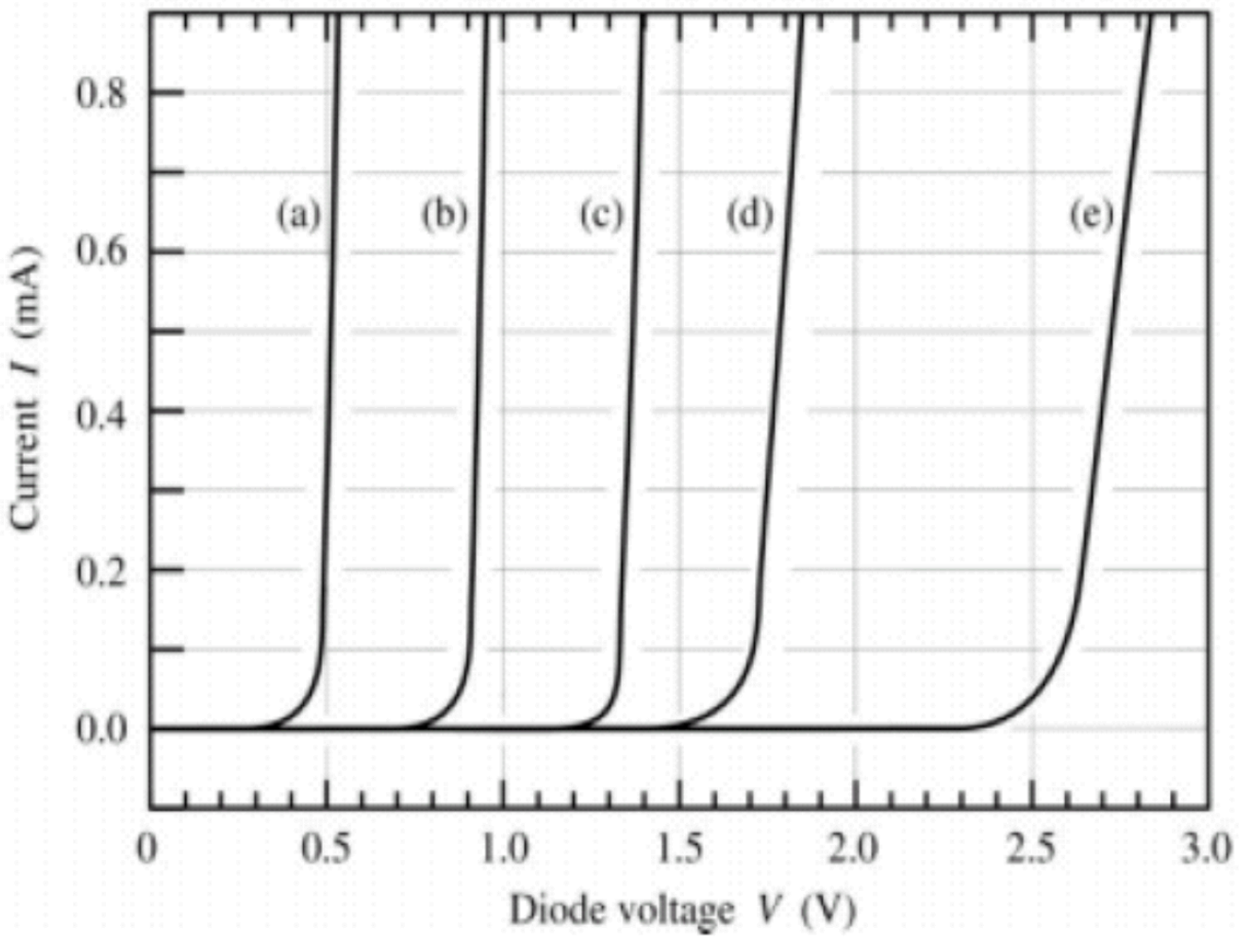
$$I = eA\left(\sqrt{\frac{D_p}{\tau_p}}\frac{n_i^2}{N_D} + \sqrt{\frac{D_n}{\tau_n}}\frac{n_i^2}{N_A}\right)\left(e^{eV/kT} - 1\right)$$

$$= I_s\left(e^{eV/kT} - 1\right) \text{ where } I_s = eA\left(\sqrt{\frac{D_p}{\tau_p}}\frac{n_i^2}{N_D} + \sqrt{\frac{D_n}{\tau_n}}\frac{n_i^2}{N_A}\right)$$ 飽和電流：沒有外加電場下的電流





Ideal Diode I-V Characteristic



$T = 300$ K

(a)	Ge	$E_g \approx 0.7$ eV
(b)	Si	$E_g \approx 1.1$ eV
(c)	GaAs	$E_g \approx 1.4$ eV
(d)	GaAsP	$E_g \approx 2.0$ eV
(e)	GaInN	$E_g \approx 2.9$ eV

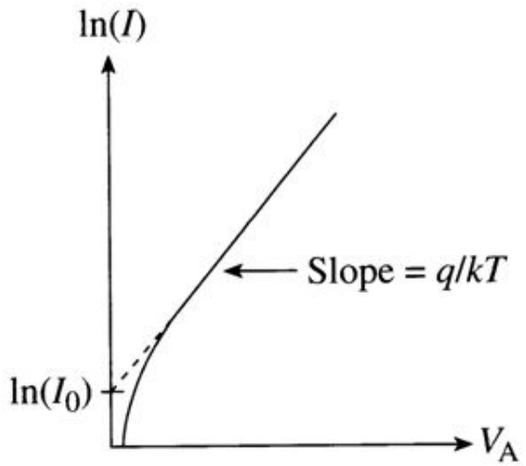
Fig. 4.2. Room temperature current - voltage characteristics of p-n junctions made of different semiconductors.

Threshold Voltage from I-V Curves

$$I = eA\left(\sqrt{\frac{D_p}{\tau_p}}\frac{n_i^2}{N_D} + \sqrt{\frac{D_n}{\tau_n}}\frac{n_i^2}{N_A}\right)\left(e^{eV/kT} - 1\right)$$

$$I = I_0(e^{\frac{qv}{nk_BT}} - 1) = I_0(e^{\frac{v}{V_T}} - 1)$$

繪製 ln(I)-V圖，斜率即閥值電壓



v 很大時， $I \approx I_0 e^{\frac{v}{V_T}}$

相除 $\frac{I_2}{I_1} = e^{\frac{v_2 - v_1}{V_T}}$ ，取 log 得 $V_T \cdot (\ln I_2 - \ln I_1) = v_2 - v_1 \Rightarrow V_T = \frac{v_2 - v_1}{\ln I_2 - \ln I_1}$

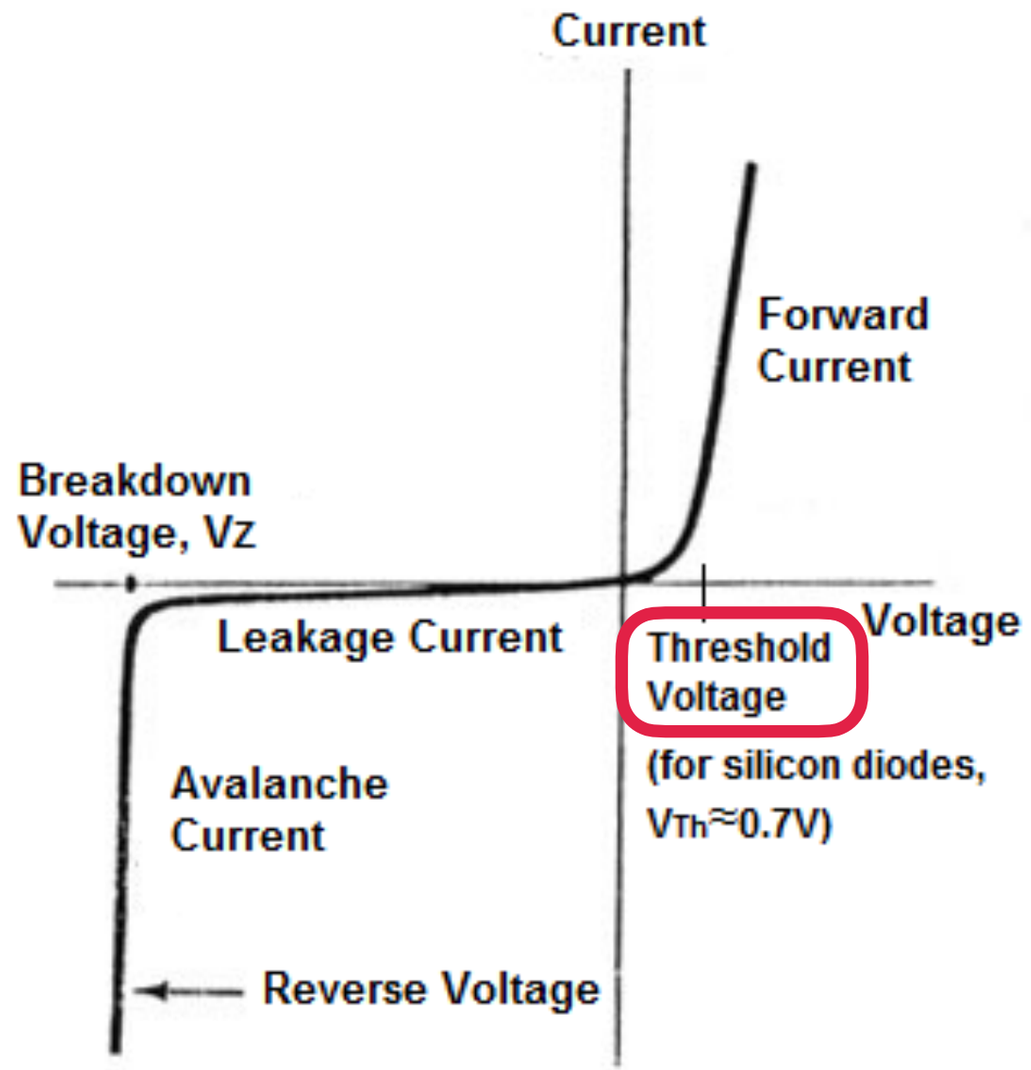
Ideal Diode I-V Characteristic

$$V_D = \frac{kT}{e} ln\left(\frac{N_A N_D}{n_i^2}\right)$$

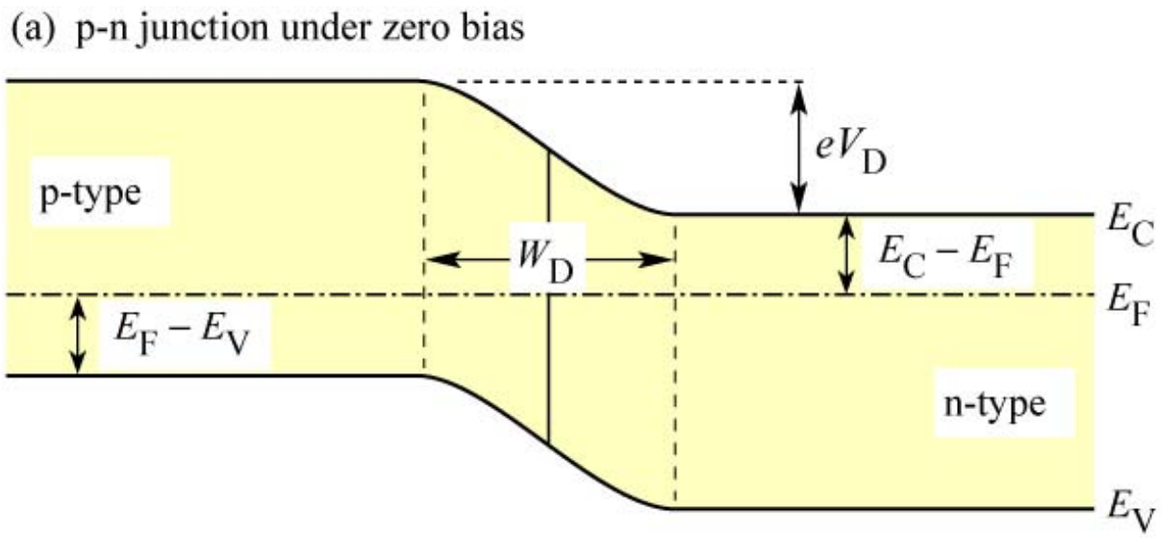
$$\Rightarrow I = eA\left(\sqrt{\frac{D_p}{\tau_p}} N_A + \sqrt{\frac{D_n}{\tau_n}} N_D\right) e^{e(V-V_D)/kT}$$

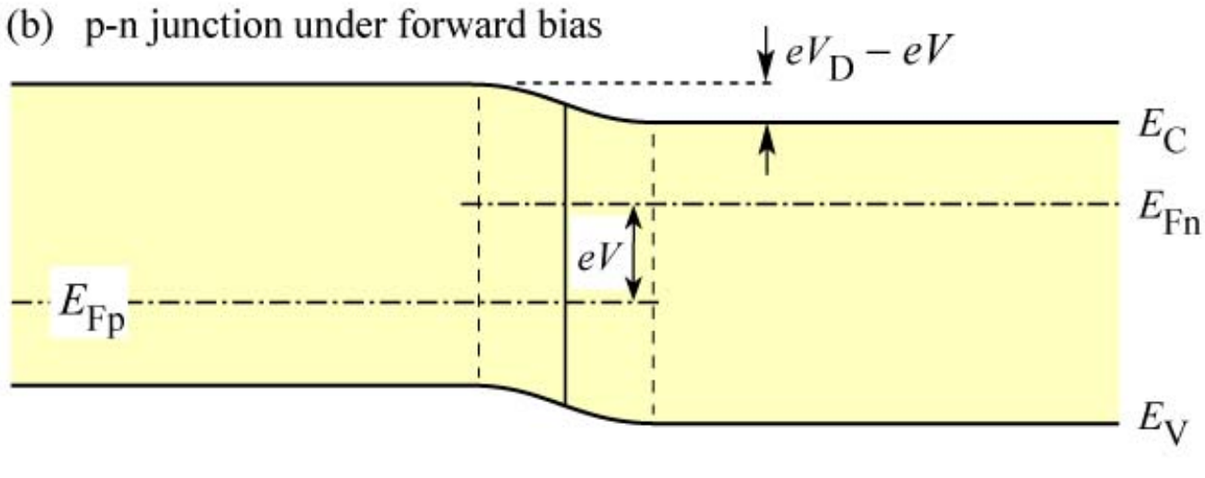
The voltage at which the current strongly increases is called "the threshold voltage" ($V_{th} \approx V_D$) (閥值電壓or導通電壓)

LED I-V Characteristic



P-N Junctions





$$eV_D + (E_F - E_V) + (E_C - E_F) = E_g$$

$$\because E_C - E_F = -kT\ln\left(\frac{n}{N_C}\right) << E_g \text{ and } E_F - E_V = -kT\ln\left(\frac{p}{N_V}\right) << E_g$$

$$\Rightarrow eV_D \approx E_g \Rightarrow \boxed{V_D \approx \frac{E_g}{e}}$$

$$E_g = hf_{LED} = \frac{hc}{\lambda_{LED}}$$

Linear Model of LED with Forward Bias

- 當順向篇壓更大的時候，內建電場被完全克服，LED的電洞電子可自由流動，I 增長趨勢接近線性。

$$V = \frac{E_g}{e} + IR + V_0$$

- R 是LED的等效內部電組，V_0 為其他電壓修正項

$$\mathrm{E}_g = \frac{hc}{\lambda}$$

$$V = \frac{hc}{e\lambda} + IR + V_0$$

Linear Model of LED with Forward Bias

- LED可被視為一個有閥值電壓的線性電組(即符合V=IR關係式)

$$\mathrm{V} = \mathrm{V}_{th} + IR$$

- 閥值電壓與(1/LED波長)成線性關係：

$$V_{th} = \frac{hc}{e\lambda} + V_0$$

Threshold Voltage and LED Wavelength

- 利用多組數據，繪製V_{th}與$\frac{1}{\lambda}$關係圖，可從斜率得普朗克常數h

$$V_{th} = \left(\frac{hc}{e}\right)\frac{1}{\lambda} + V_0$$

- 在此關係式中，V_{th}與 $\frac{1}{\lambda}$ 的斜率為 $\frac{hc}{e}$，而截距為V_0。

實驗器材與注意事項

實驗器材

- 紅、橘、黃、綠、藍、紫 LED 各一顆
- 三用電表*2 ：一台用來測電壓V，另一台測電流I
- 鱷魚夾接線
- 2kΩ 可變電阻*1
- 直流電供應器*1

三用電表

測電壓：

並聯

測電流：

串聯

＊從大檔往小檔位轉

直流電源供應器

＊限電流：

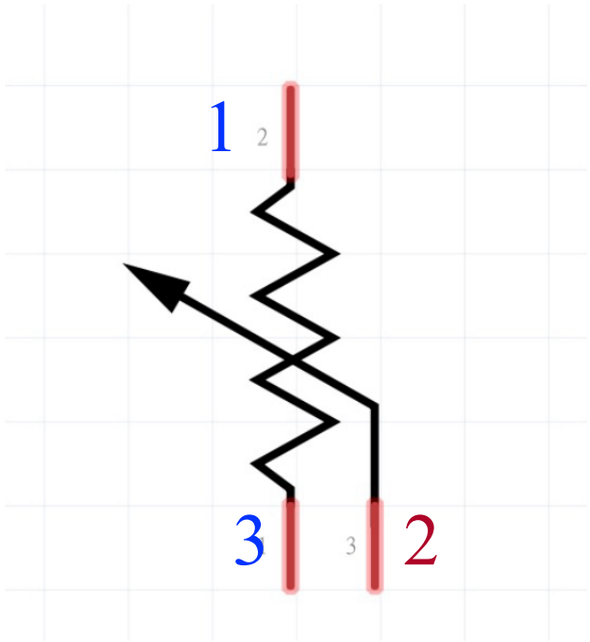
避免電流太大燒了電供or電子元件

直流電源供應器

設定限電流：

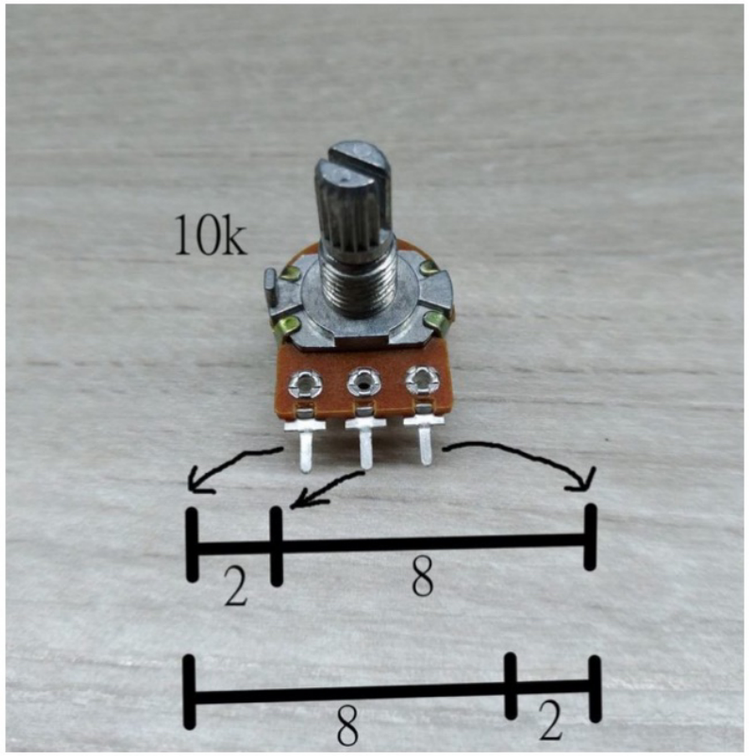
1. 接短路
2. 開小電壓，確保電流不會超過電源供應器的最大電流
3. 轉A紐，調到需要的限電流大小
4. 調好後直接斷路

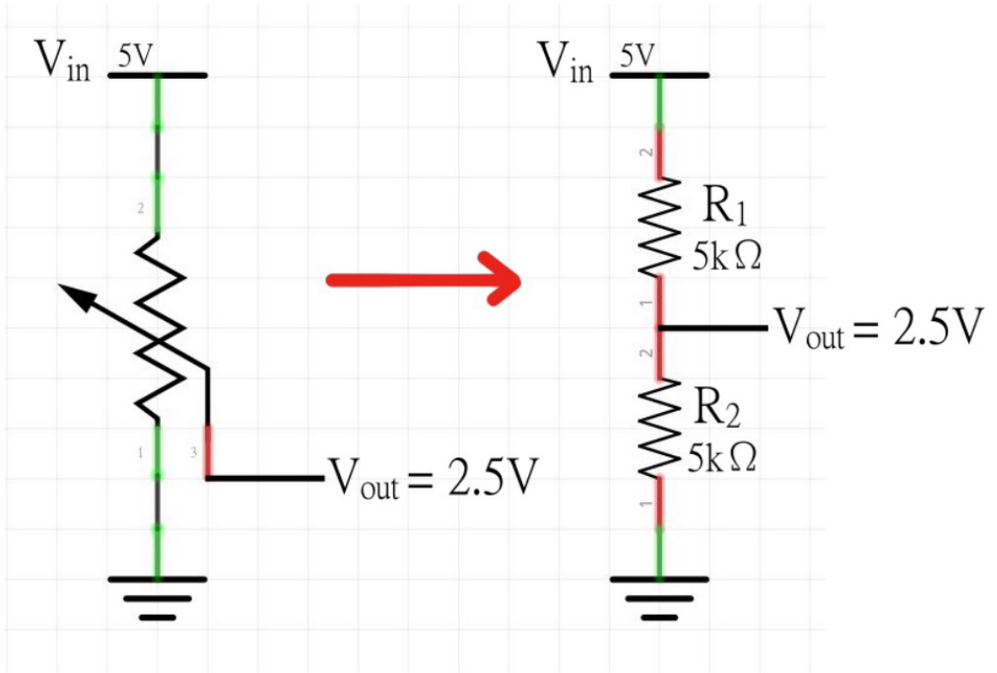
可變電阻 



＊電線接12 or 23，另一端接地 (以免燒掉)

可變電阻





圖中為可變電阻調至中間位置，同等右邊的電阻串聯電路

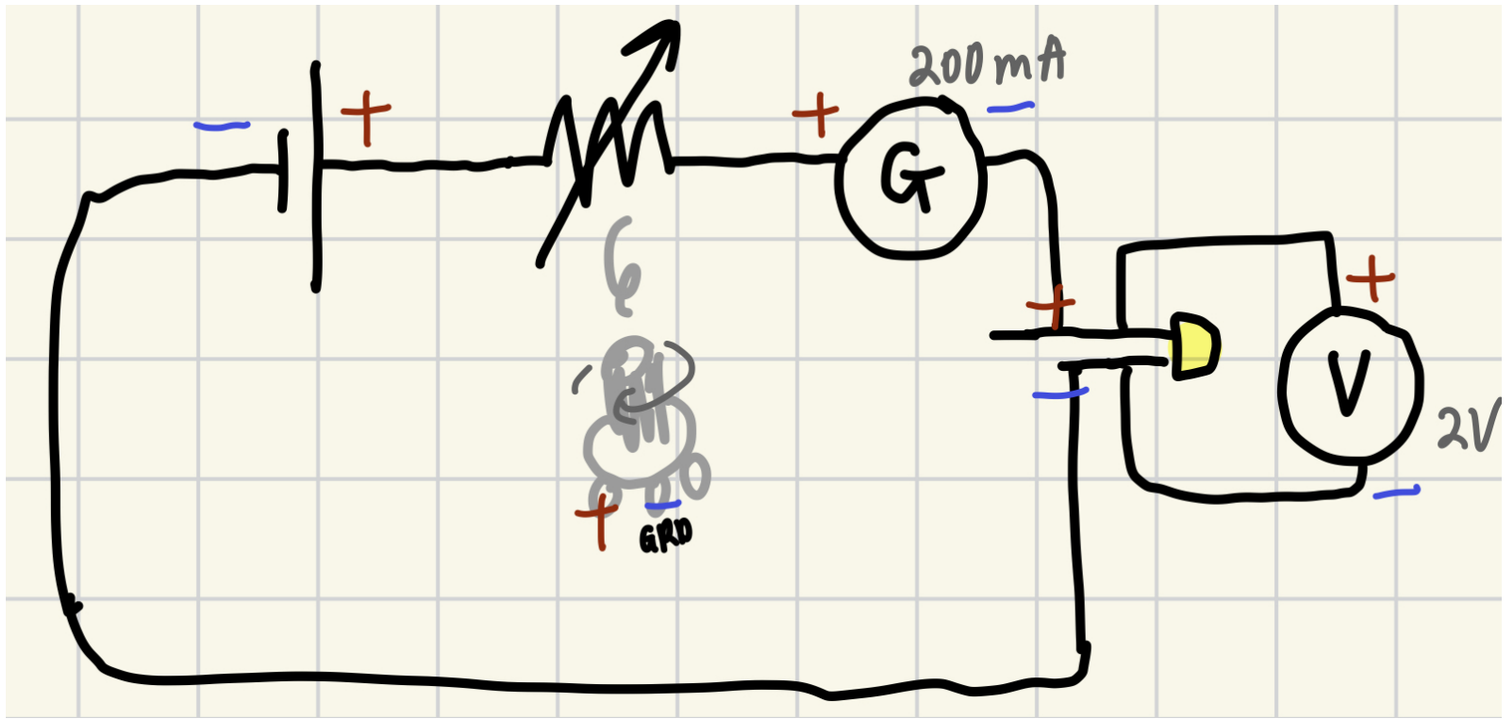
以10kΩ的可變電阻為例，若是量測到左對中是2kΩ ，那麼中對右就會是8kΩ ，左對右(兩者相加)就會是固定的總阻值10kΩ。

轉動旋鈕使滑動端往右邊移動，就可以調整成左端為8 kΩ ，右端為2 kΩ

電路

調電壓的方法：

1. 調電供
2. 固定電供V，轉可變電組



其他注意事項

- LED長腳接正極，短腳接負極
- 由小電壓(約1.5V)開始測量，慢慢將偏壓調大
- 一顆LED大約測量30個數據點
- 順向偏壓較大時，電表讀值會有浮動，此時請一調好電壓就果斷紀錄數據！
- 如果LED在閃爍或是發光不穩定，可能代表它快燒掉了
  記得趕快把電壓調小讓LED休息一下