享樂實作-2
減輕負荷的實作模組分享

感謝:

台灣物理學會暨物理實作平台小組

台灣師大物理系

國立臺灣師範大學物理系(退休)
陸健榮

減輕負荷

減輕:

- 學生的學習負荷:認知負荷(Cognitive Load)
- 教師的資源負荷: **錢**、人員、器材、維護...

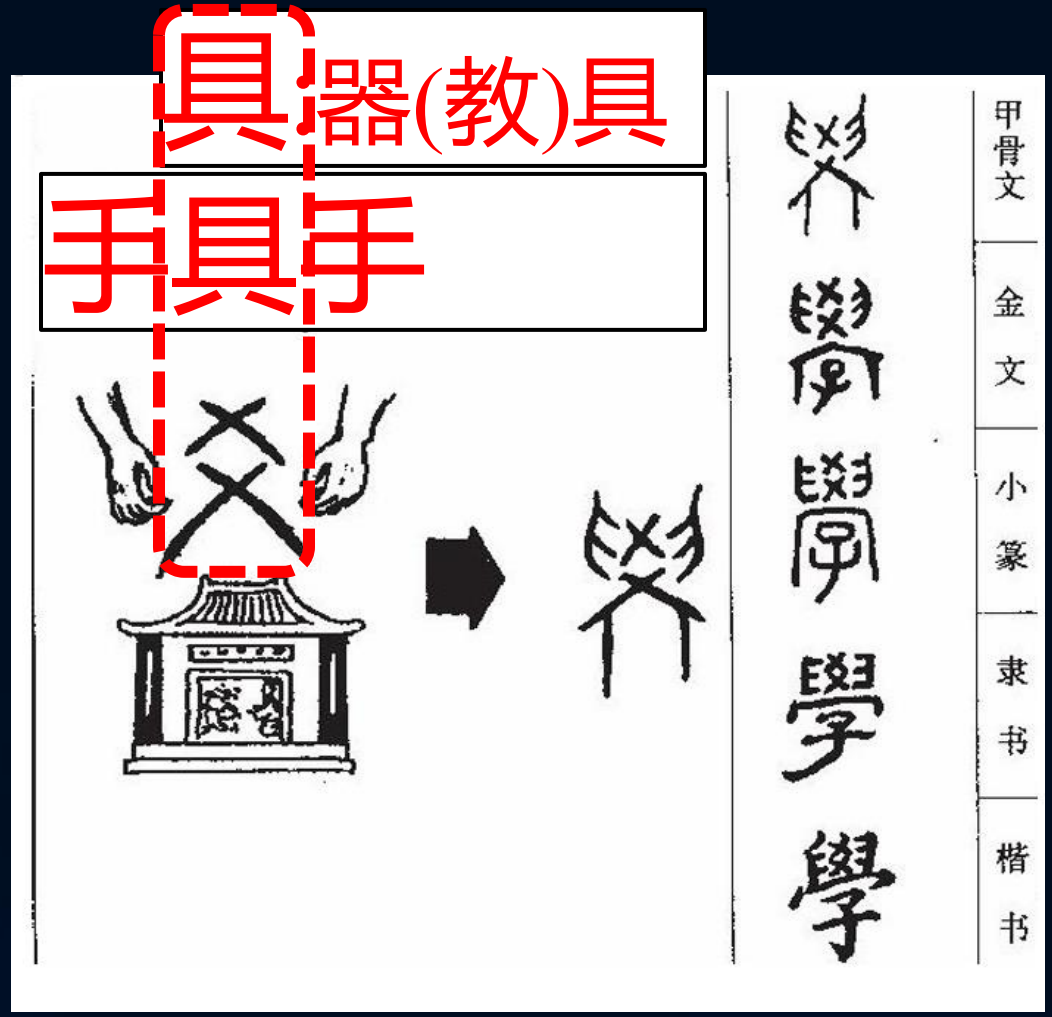
因「材」施教:

學生材(先天、後天)資質

教師材:環境(學校、社會...)資源。窮則變，變則通

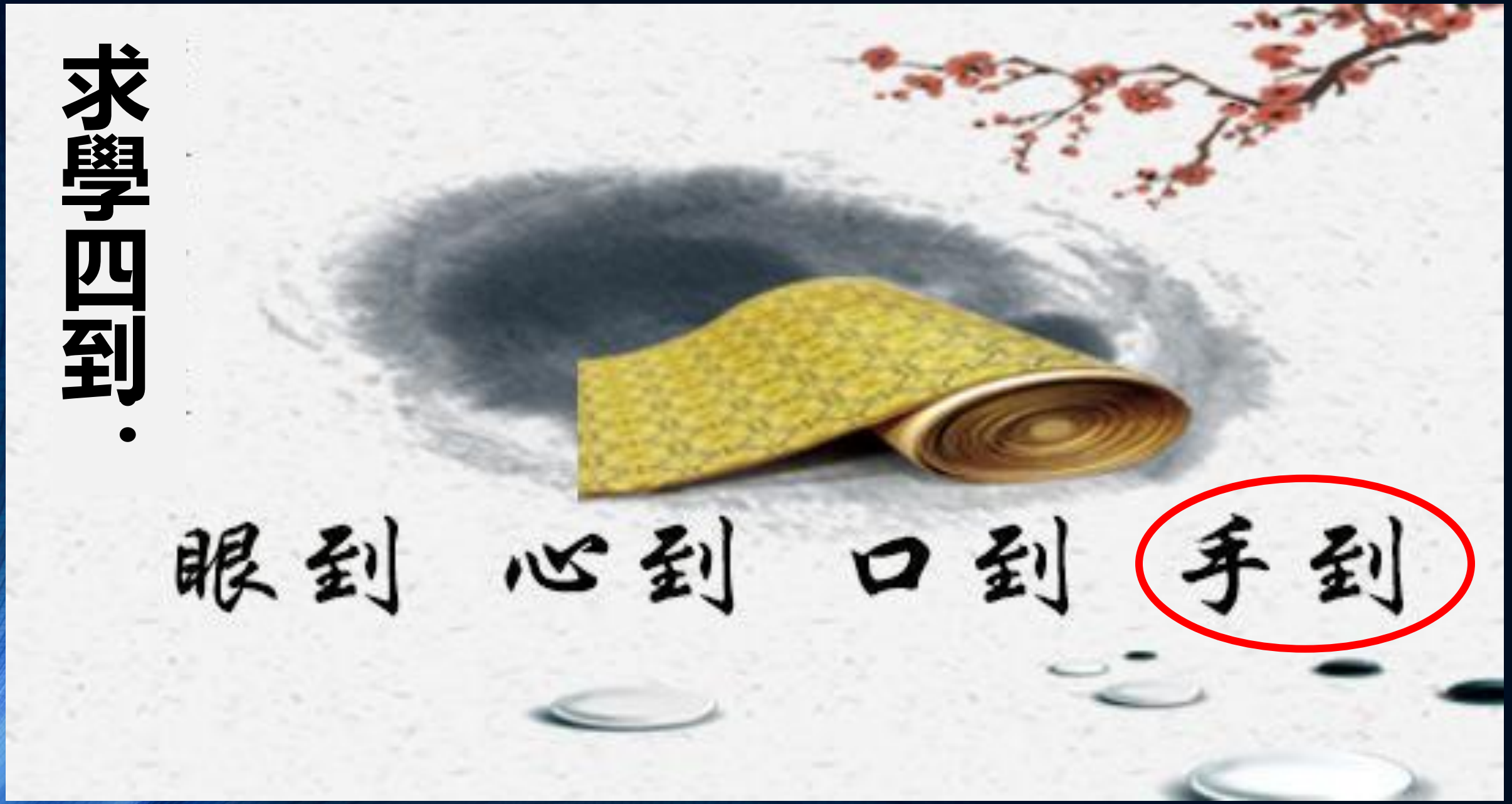
https://youtube.com/shorts/4ySVl24Rp_Y?si=vJisg1SlFl8pilNv

學: 動手實作

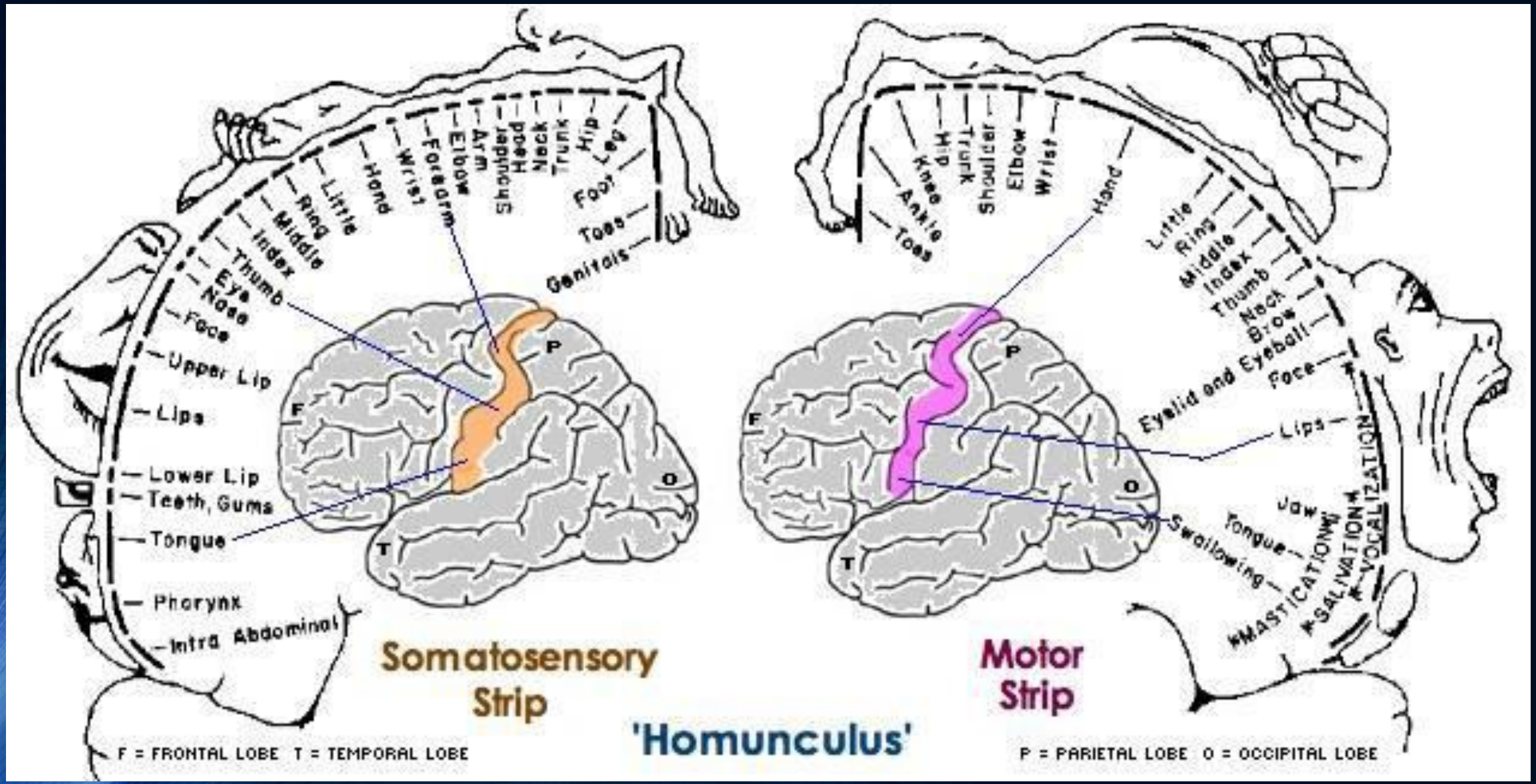


字源其说9——“学”

求學四到：



大腦皮質功能娃娃 (Cortex homunculus)



大腦皮質功能娃娃(Cortex homunculus)

Sensory Homunculus and Motor Homunculus
Museum of Natural History, London

Cognitive Load Theory (CLT)
認知負荷原理

CLT assumes a **limited working memory** that stores about seven elements but operates on just two to four elements. It is able to deal with information for no more than a few seconds with almost all information lost after about 20 s unless it is refreshed by rehearsal.

CLT: Effects and guidelines to create learning materials

1. Goal free effect: 避免標準答案
2. Worked examples effect: 部分解…
3. The variable example effect: 變化範例…
4. Problem completion effect: 全解要附未解挑戰.
5. Modality effect: 多管道，如視、聽….
6. Split-attention effect: 分心...)
7. Redundancy effect:冗餘效應…
8. Element interactivity effect: 多單元互相影響....
9. Isolated interacting elements effect: 獨立(免互相影響)單元…
10. Imagination effect: 想像效應….
11. Expertise reversal effect: 專家反轉…
12. Guidance fading effect: 漸少指導….

認知負荷

國家教育研究院 National Academy for Educational Research 電子報

第92期 2014-07

請輸入關鍵字..

科技是發展還是阻礙學生學習？—「國際認知負荷理論工作坊」側寫

| 李涵鈺

【文／教科書發展中心專案研究人員　李涵鈺】

John Sweller在80年代提出認知負荷理論（Cognitive Load Theory）後，隨即引起國際上的重視；近年來，在數位資訊科技的推波助瀾下，多元訊息與媒體組合雖然豐富了感官經驗，但也隱藏可能產生認知超載與干擾的情形，形成無謂的認知負荷，有鑒於認知負荷理論對學習與教學及教材設計的重要性，國際認知負荷理論學會於今（103）年6月24-26日在臺灣舉辦第七屆認知負荷理論國際研討會，並在6月23日舉辦國際認知負荷理論工作坊，由中央大學學習與教學研究所主辦。

瑞典、芬蘭...學校棄用平板回歸「紙本書寫」

Sweden says back-to-basics schooling works on paper

In 2009, Sweden embarked on a groundbreaking educational reform, ….

after 15 years, the Swedish government …. reintroduce paper textbooks into schools.

Concerns… decline in foundational skills such as **reading and writing**. …students struggled with **concentration and memory retention** …. hindered students' ability **to comprehend complex texts** effectively.

日本腦科學專家十年研究警示:
滑手機恐致發育停滯
(學力表現仍不如幾乎不讀書)

2023 Apr 12;28:22. doi: 10.1265/ehpm.22-00245

Cross-sectional associations between early mobile device usage and problematic behaviors among school-aged children in the Hokkaido Study on Environment and Children's Health

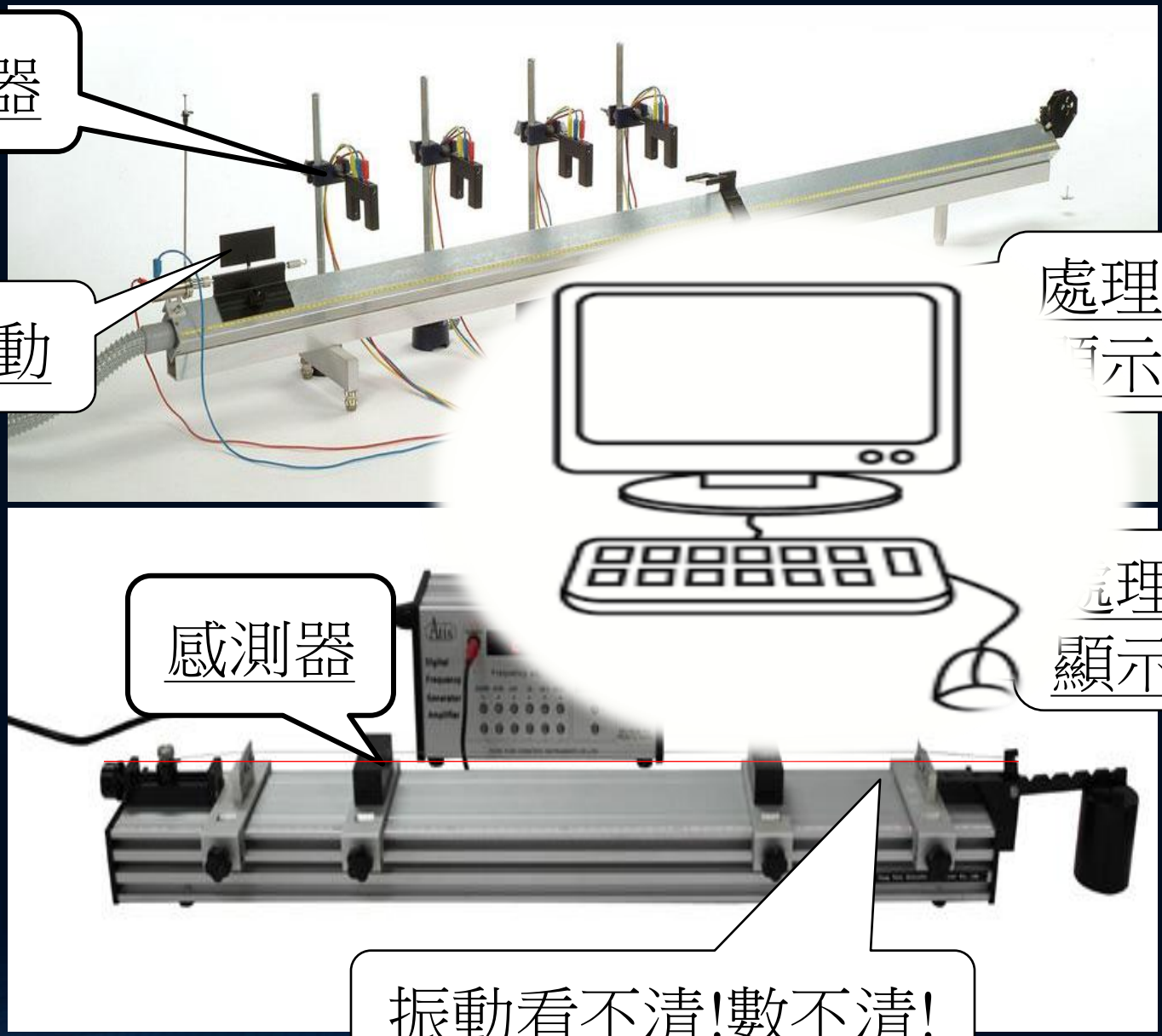
Screen time has limited effects on toddler's development: Japan study

KYODO NEWS - Mar 19, 2023 - 10:27 | All, Japan

套裝儀器:

酸葡萄:
維護不易、
價格昂貴、
實作漸少、

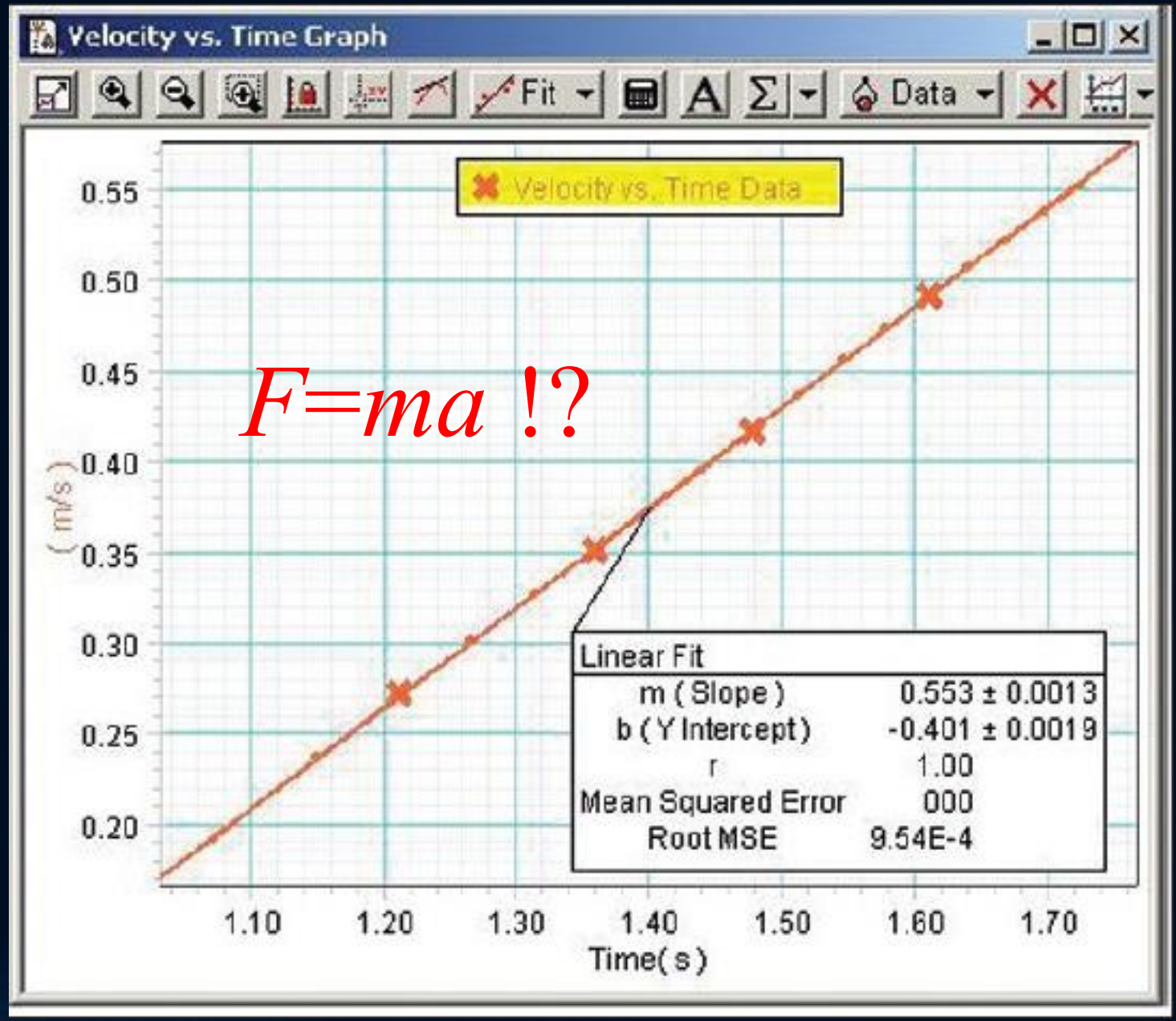
認知負荷原理:
新手效應、
全解無挑戰、
專家反轉效應、
動機效應?



套裝儀器:

酸葡萄:
維護不易、
價格昂貴、
實作漸少、

認知負荷原理:
新手效應、
全解無挑戰、
專家反轉效應、
動機效應?



CLT- Expertise Reversal Effect

Instructional techniques
that are effective with inexperienced learners
can **lose their effectiveness** and even have
negative consequences
when **used with more experienced learners**.
We call this phenomenon the **expertise reversal effect (專家反轉效應)**.

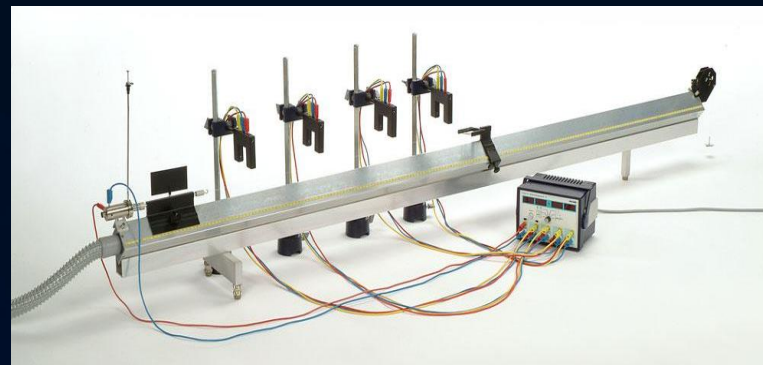
大費周章驗證 $F = ma$?! 有教學成效嗎?
能引起動機嗎?

減輕資源負荷

套裝儀器

因財施教:
產業元件(量產、價廉、通用、耐用)
善用DIY與Maker 資源
與生活(職業)實務連結

酸葡萄:
維護不易
價格昂貴
實作漸少



CLT- Real-life tasks effect

Real-life tasks should be the driving force for complex learning:
Complex learning is a lengthy process requiring learners' motivational states (jobs) and levels of expertise development to be taken into account.

減輕負荷的實作

主題:

力學

電磁學

熱學

光學

量子科學

Cantilever 懸臂

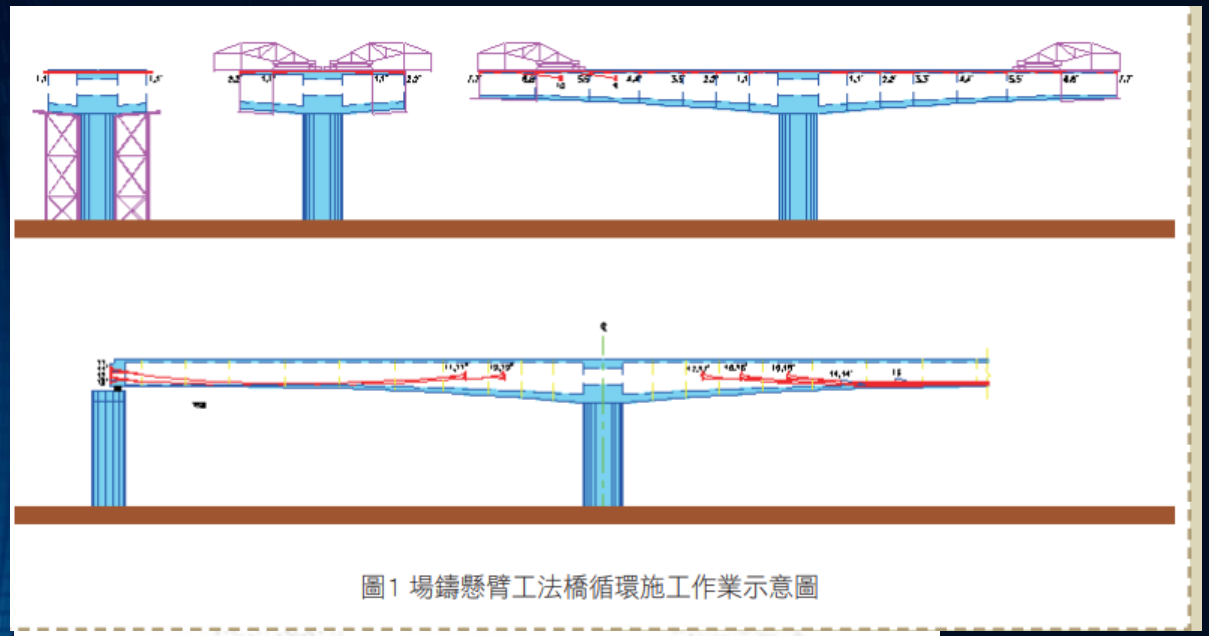
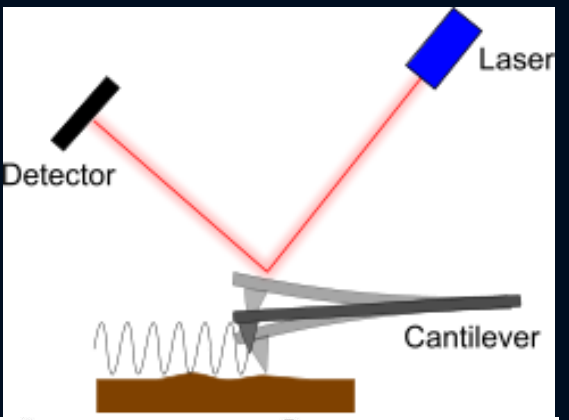
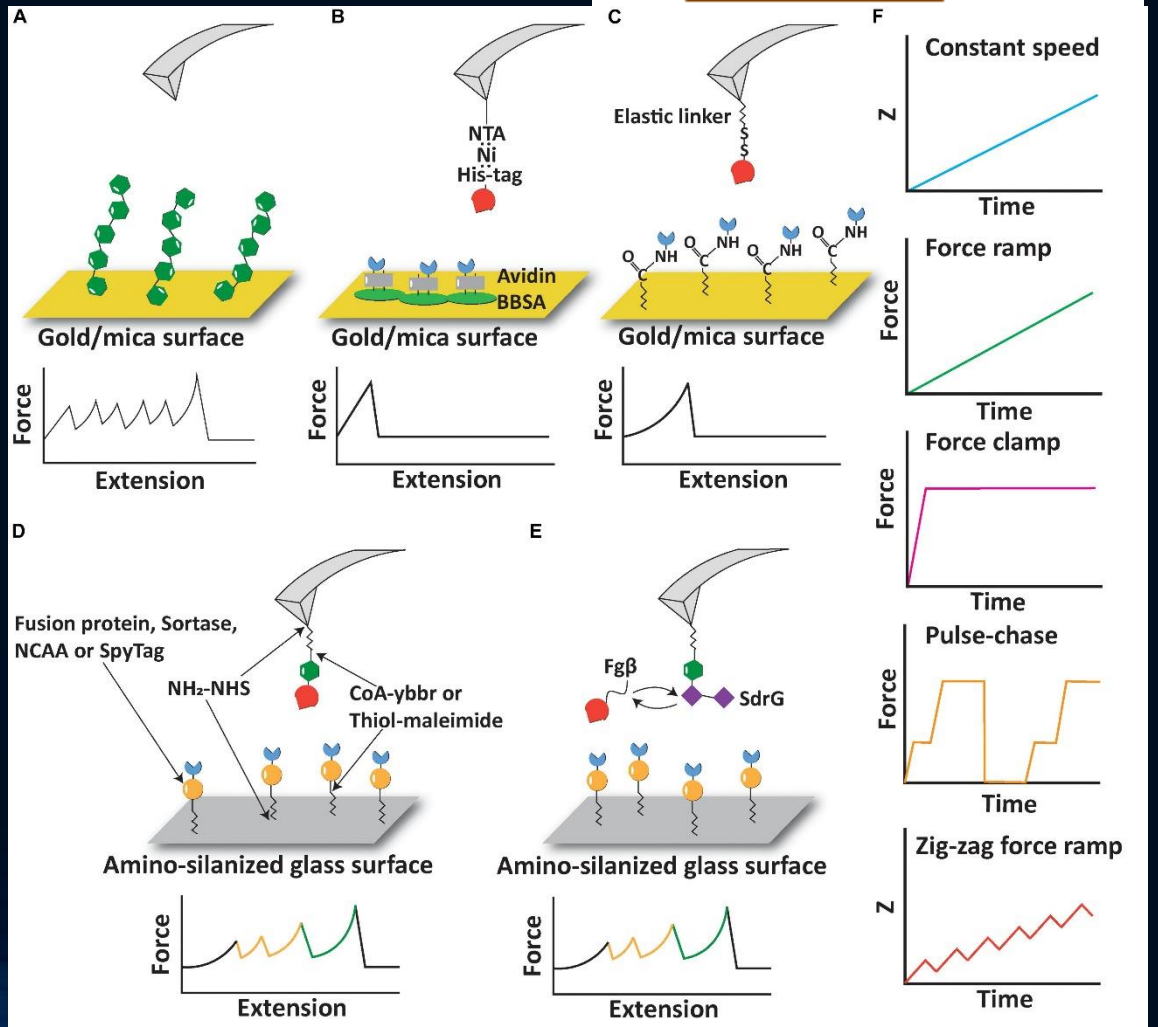


圖1 場鑄懸臂工法橋循環施工作業示意圖





實作教育資源分享與推廣

競賽:地方、國家、民間、國際資源

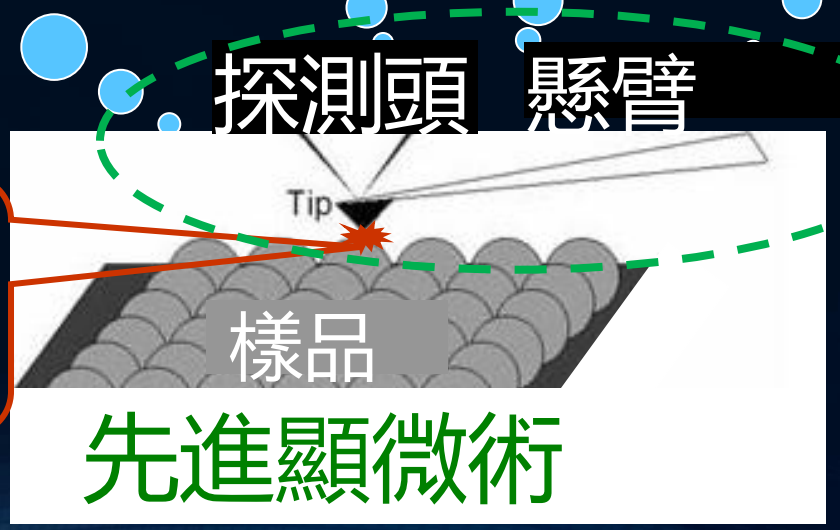
→少數參賽者

高中
自然科學
競賽

國際
物理辯
論賽
IYPT

國際物
理奧林
匹亞
IPHO

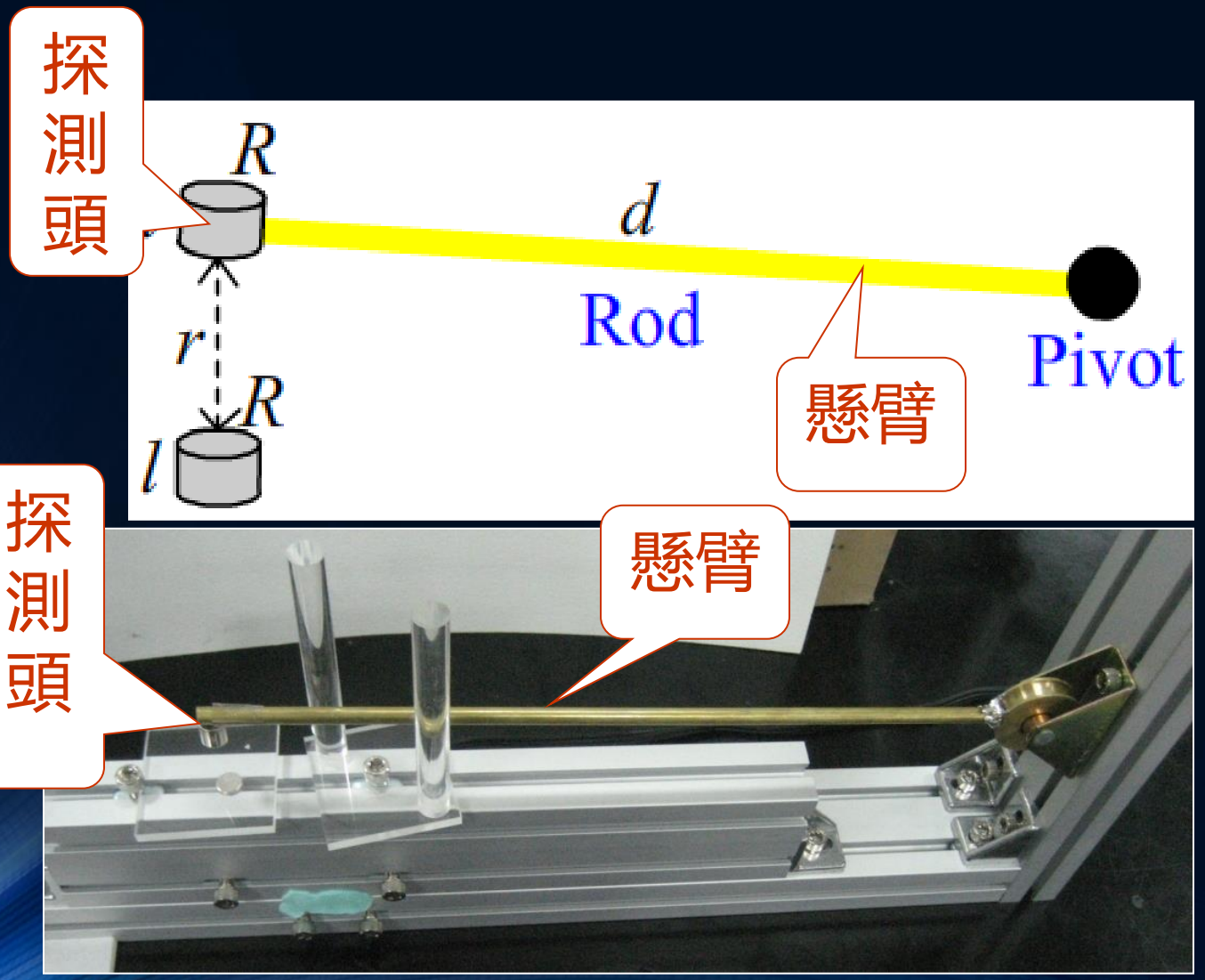
國際
科展
ISEF

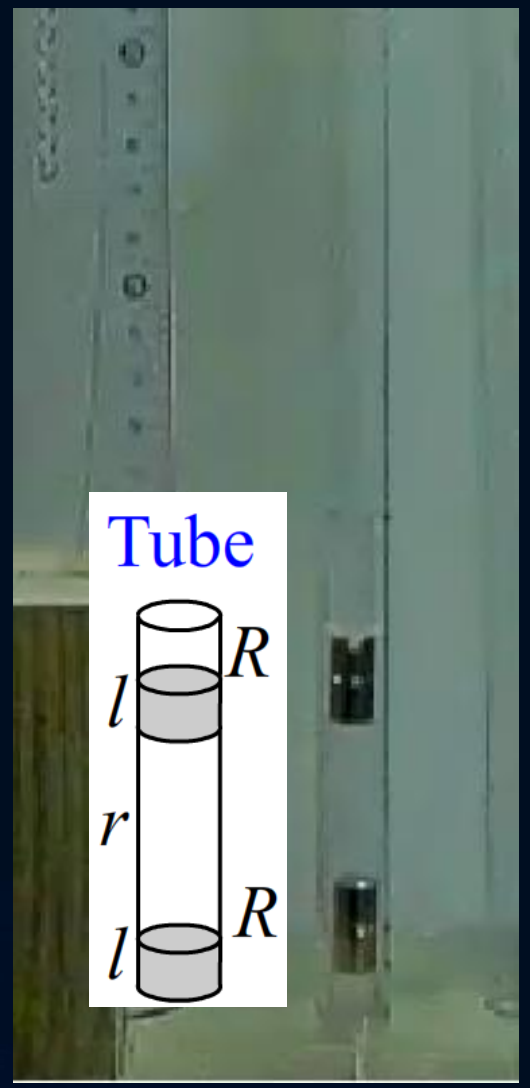


The Nobel Prize in Physics 1986

IYPT 2010 Magnetic Spring

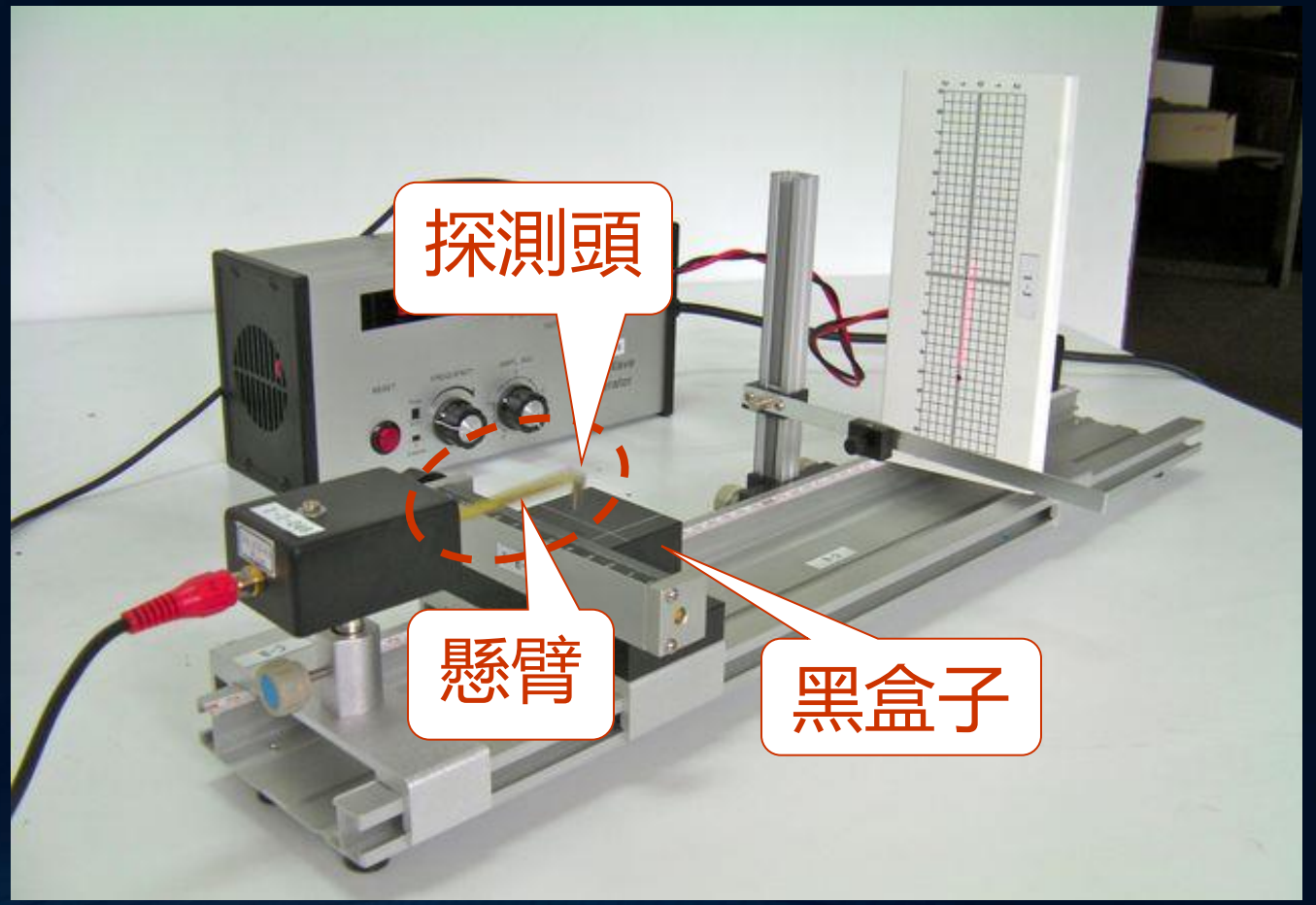
物理辯論賽與懸臂力學(先進顯微術?)相關主題





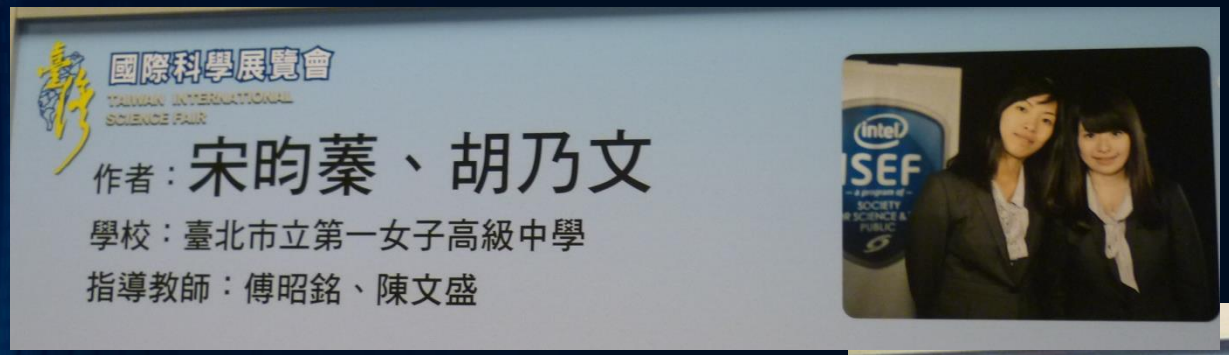
APHO 2010 Megnetic Probe

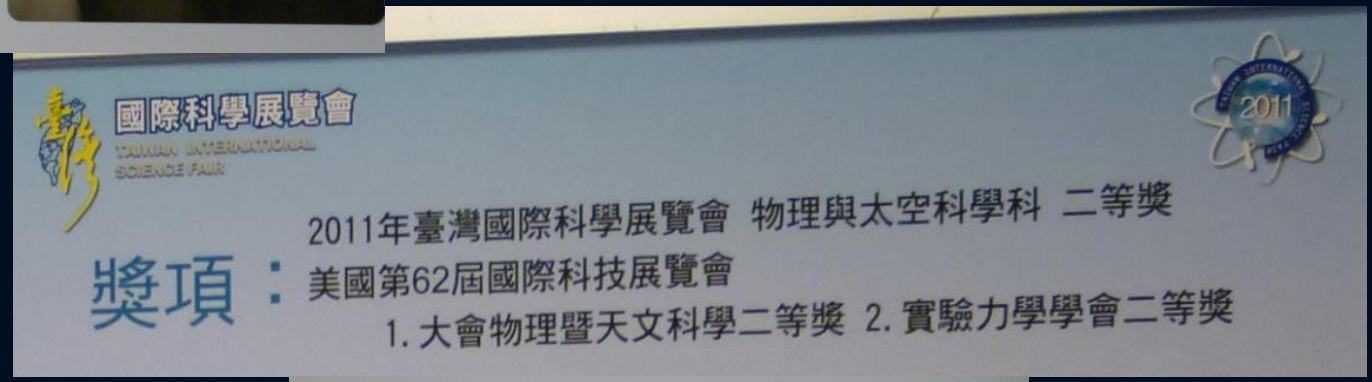
物理奧林匹亞與懸臂力學(先進顯微術?)相關主題

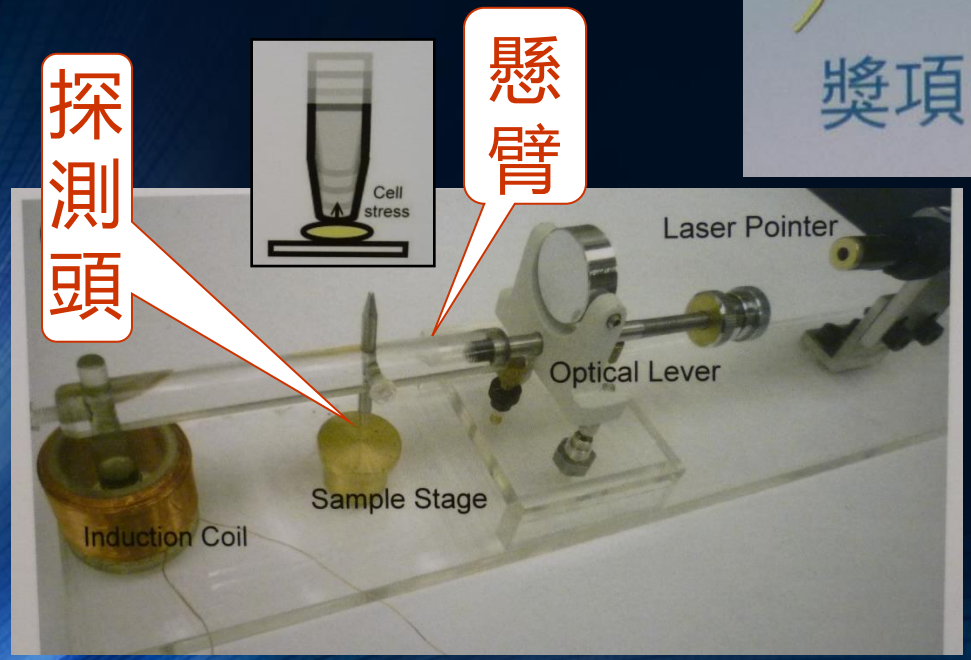


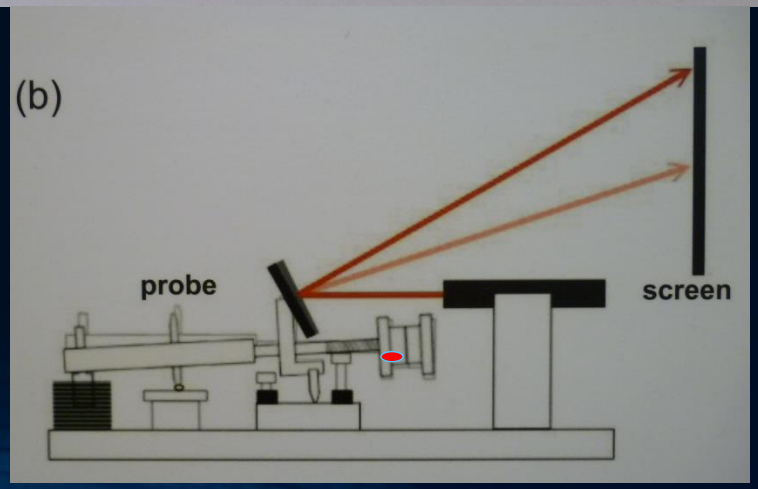
2011 ISEF
自製電磁力振盪器探討斑馬魚卵軟結構生物力學特性

國際科展賽與懸臂力學
(先進顯微術?)相關主題

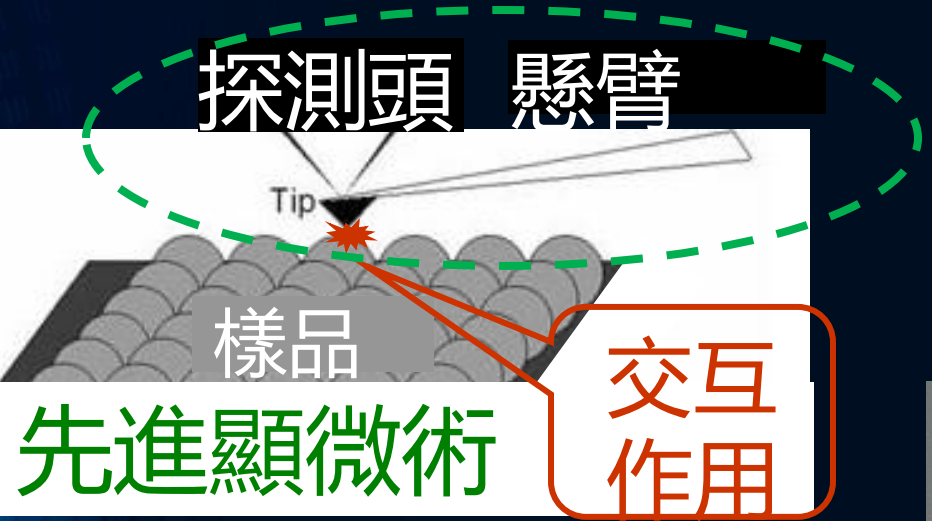


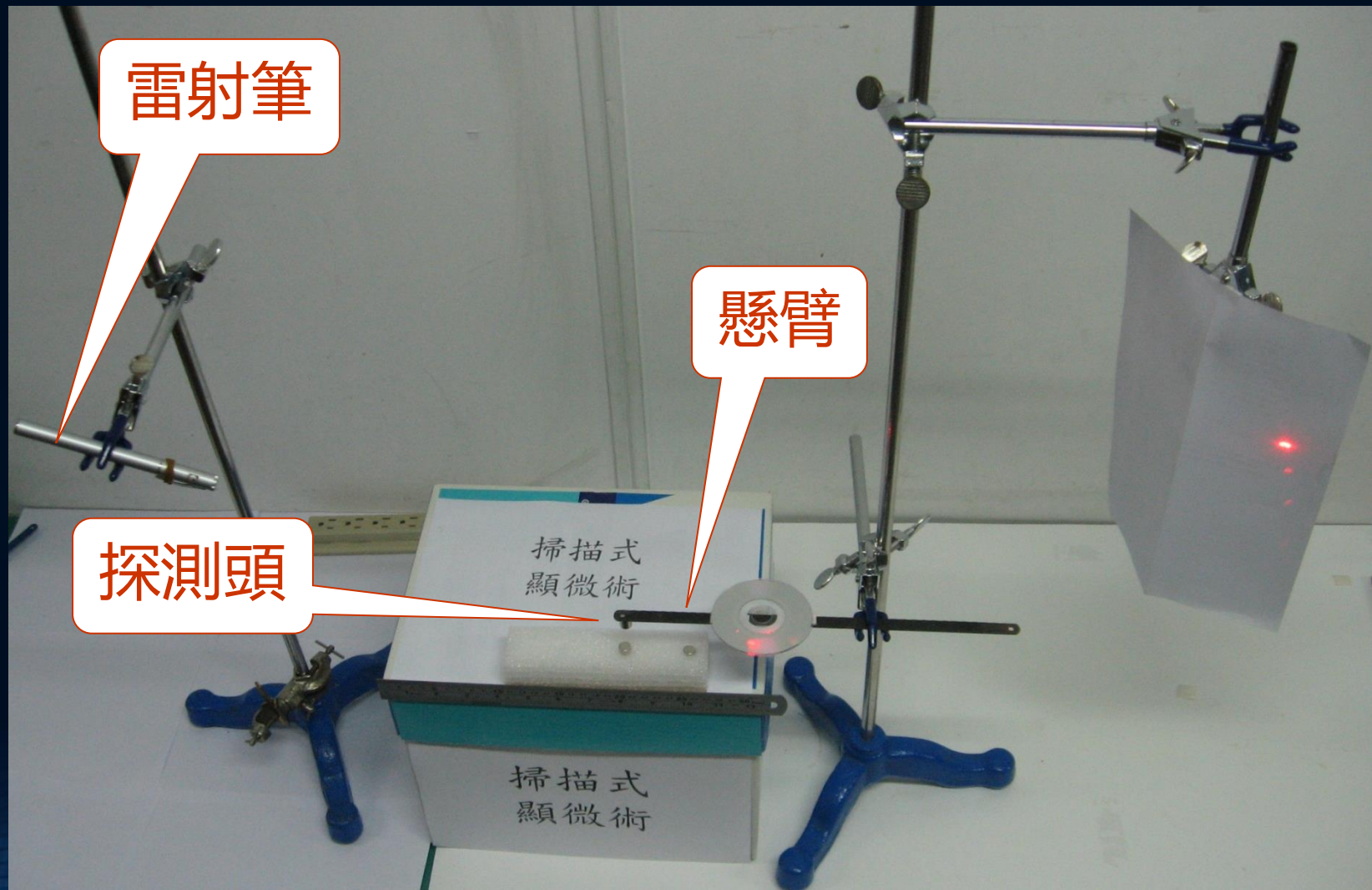






懸臂力學應用於先進顯微術演示實作





懸臂力學應用於先進顯微術演示實作

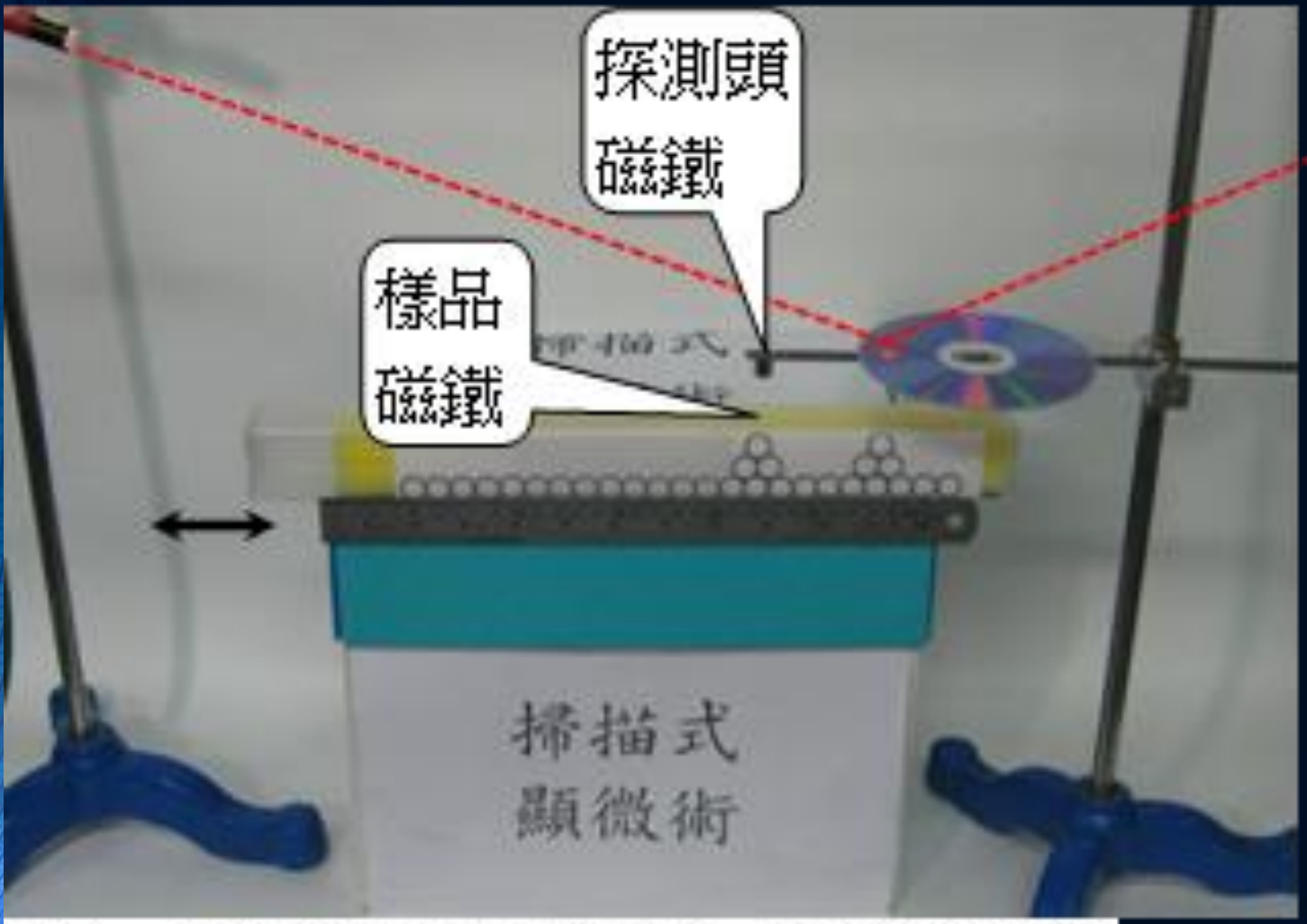


圖 1　掃描式顯微術課堂示範實驗照片

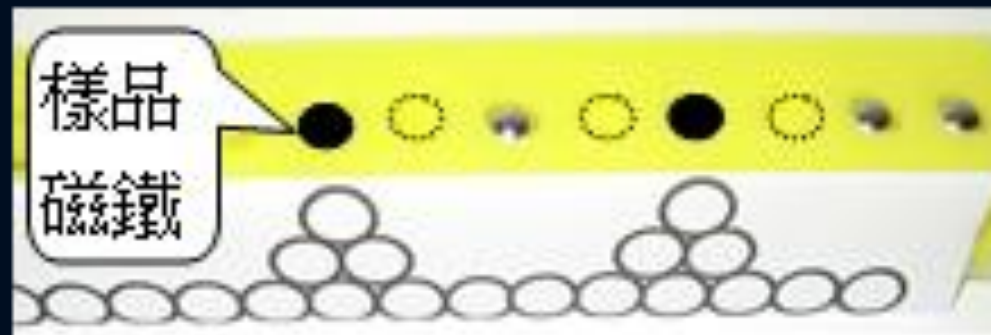
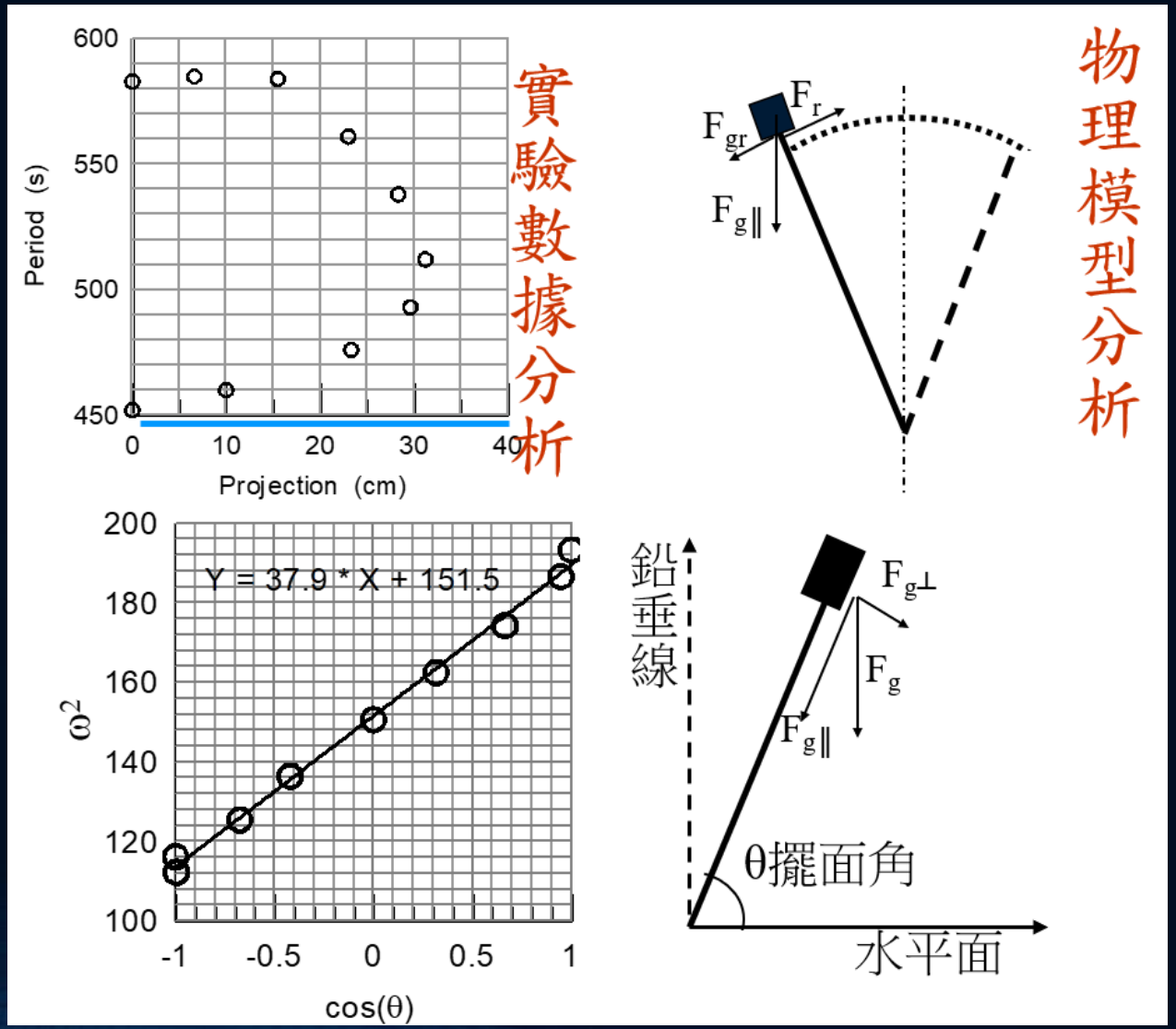


圖 2　上：利用短六腳銅柱將鋼片鎖在固定座上。
下：樣品磁鐵位置。

懸臂振動與外力場(重力場)偵測

示範、實驗或專題

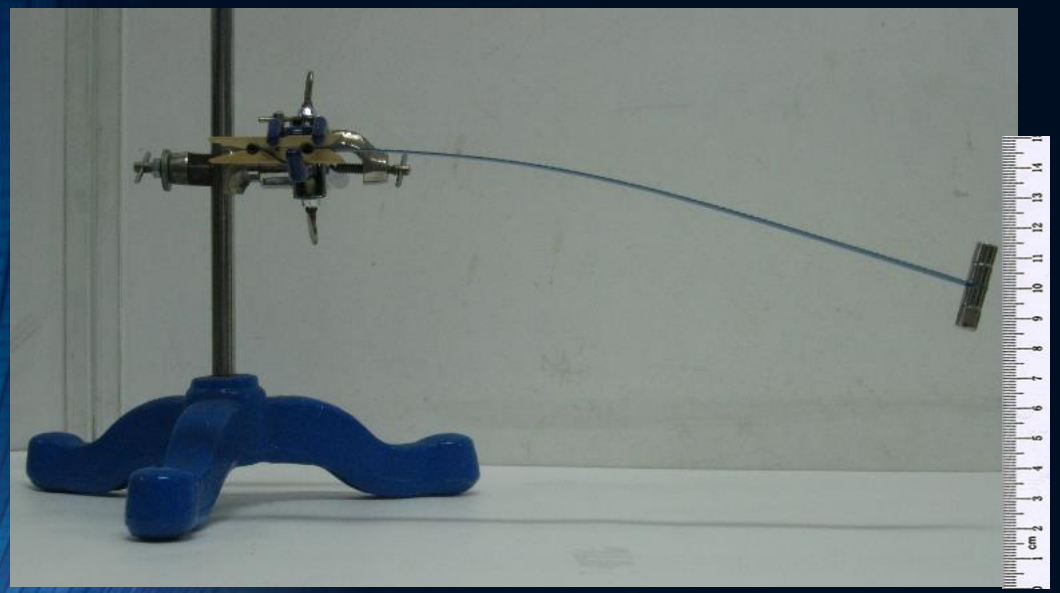
數據與建模:



中學教師研習

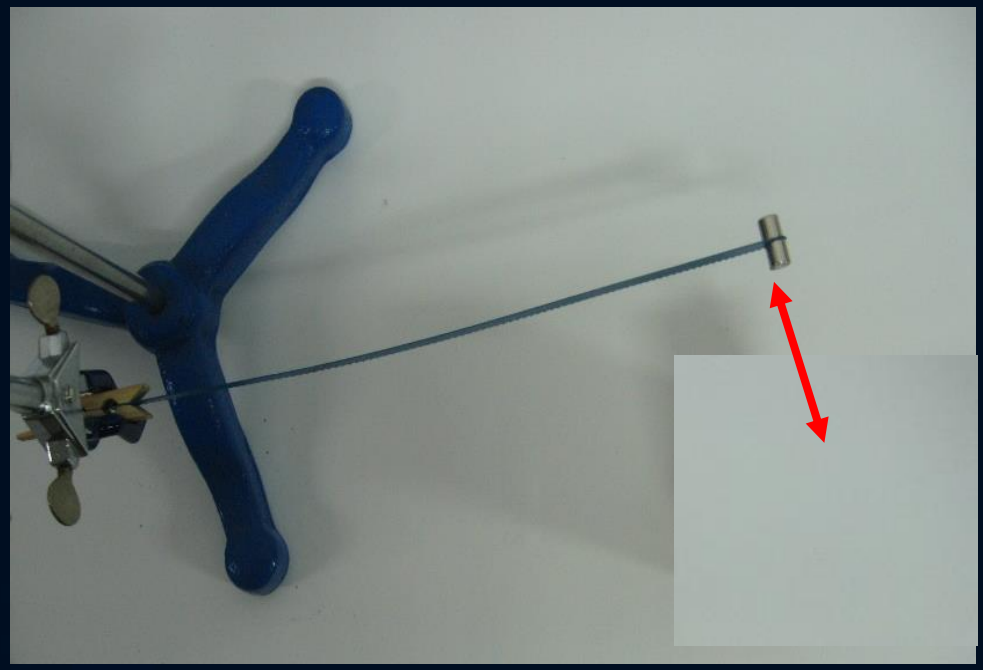
減輕負荷:從簡而繁

◎靜態(彎曲)模式



$\Delta y =\propto m?$

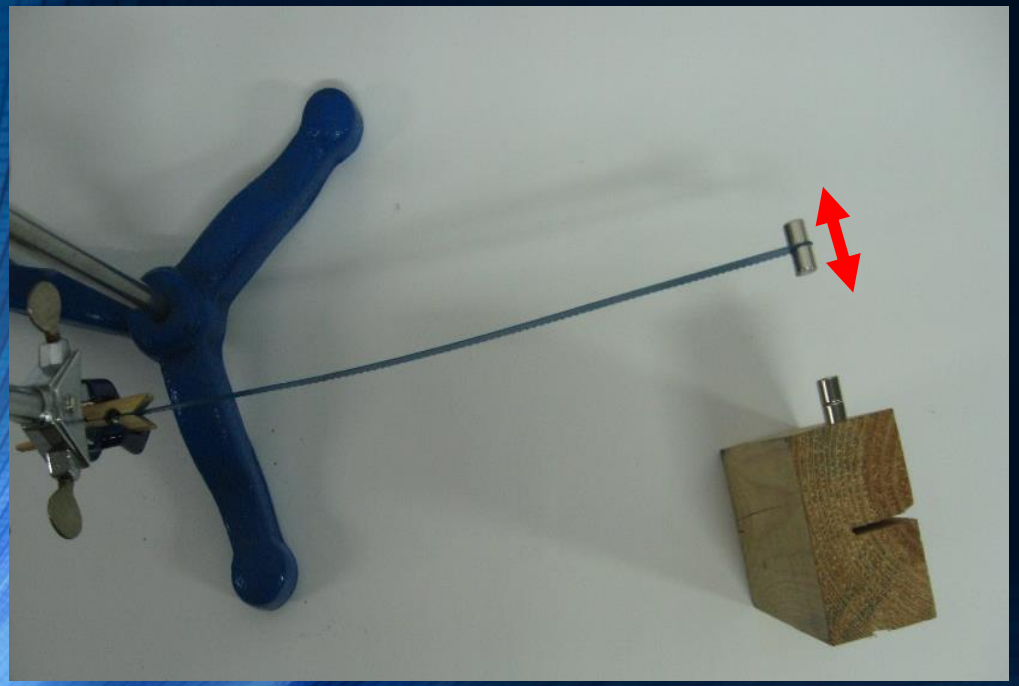
◎動態(振動)模式

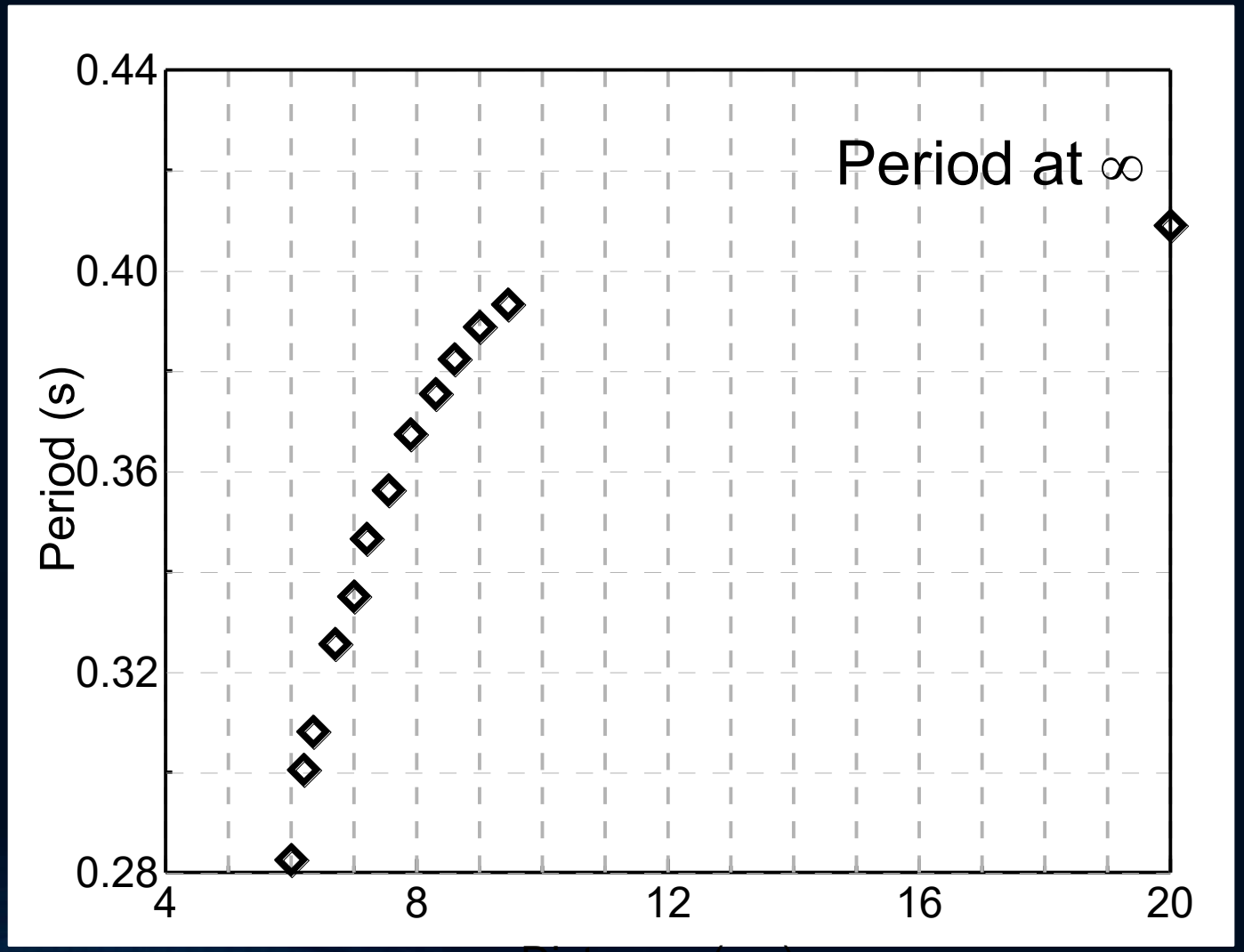


$\mathrm{T} =\propto \sqrt{m}?$

運用懸臂力學實作探究電磁學:
Dipole-Dipole interaction
偶極-偶極作用

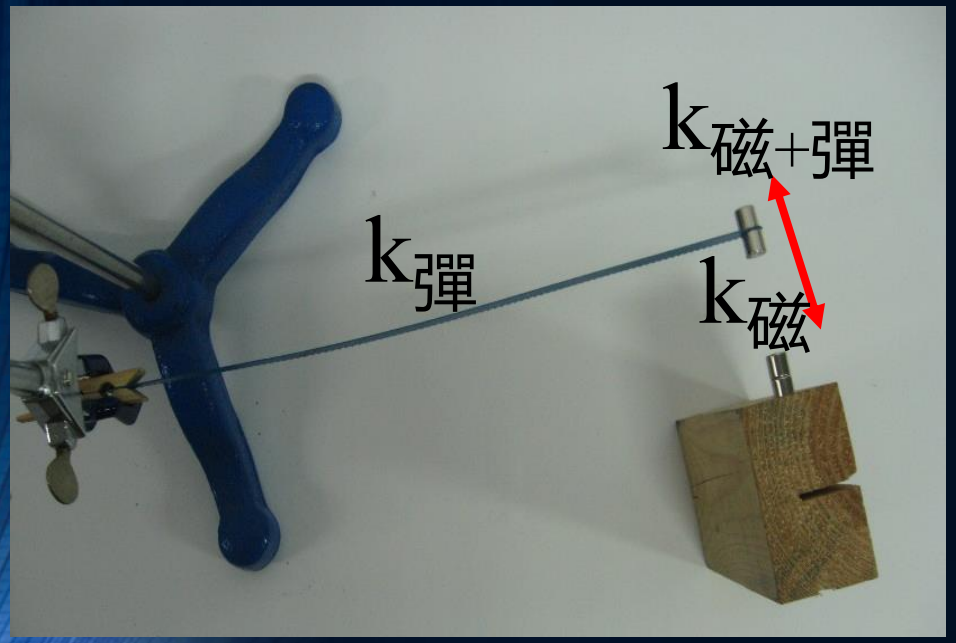
◎動態模式

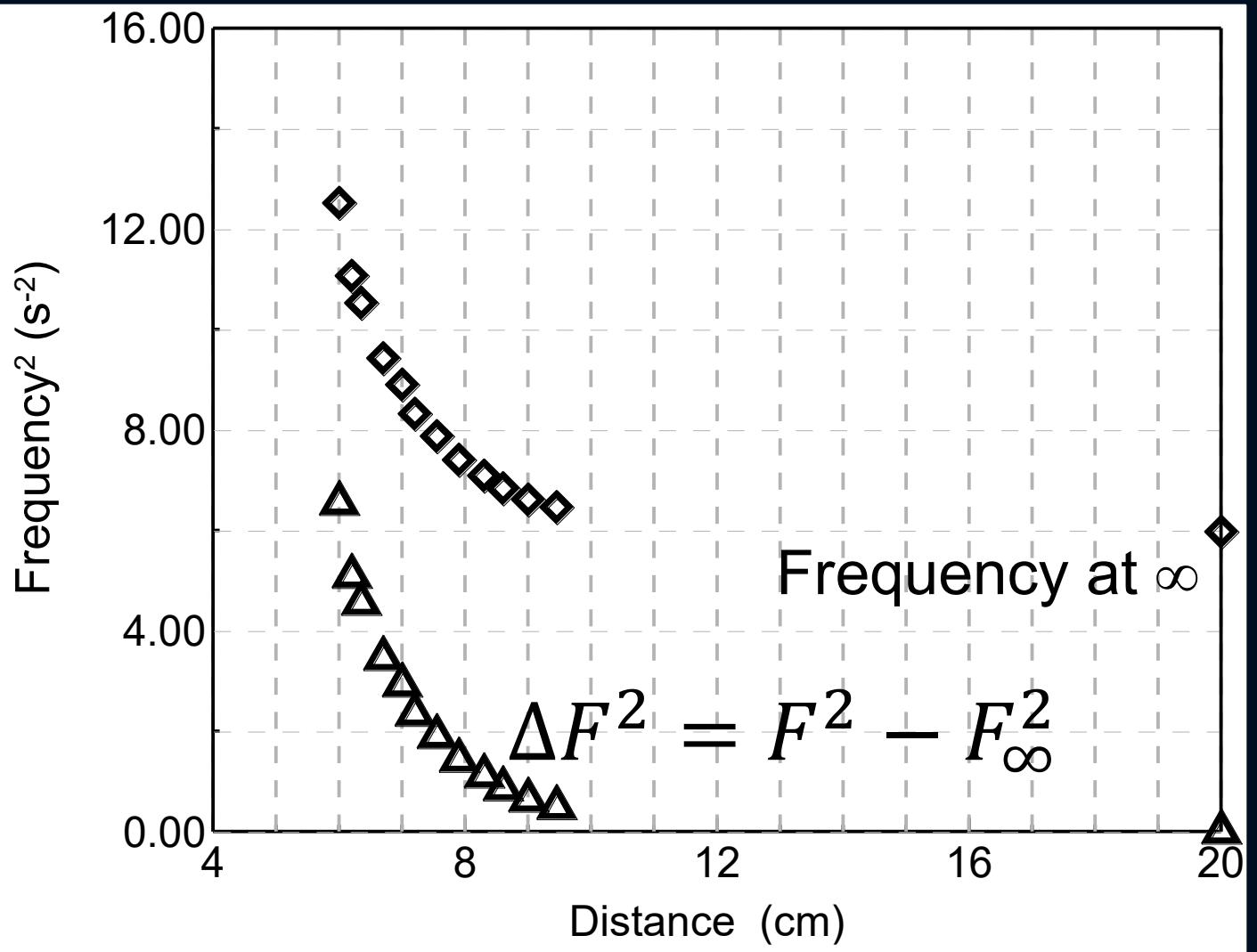




偶極-偶極作用

◎動態模式



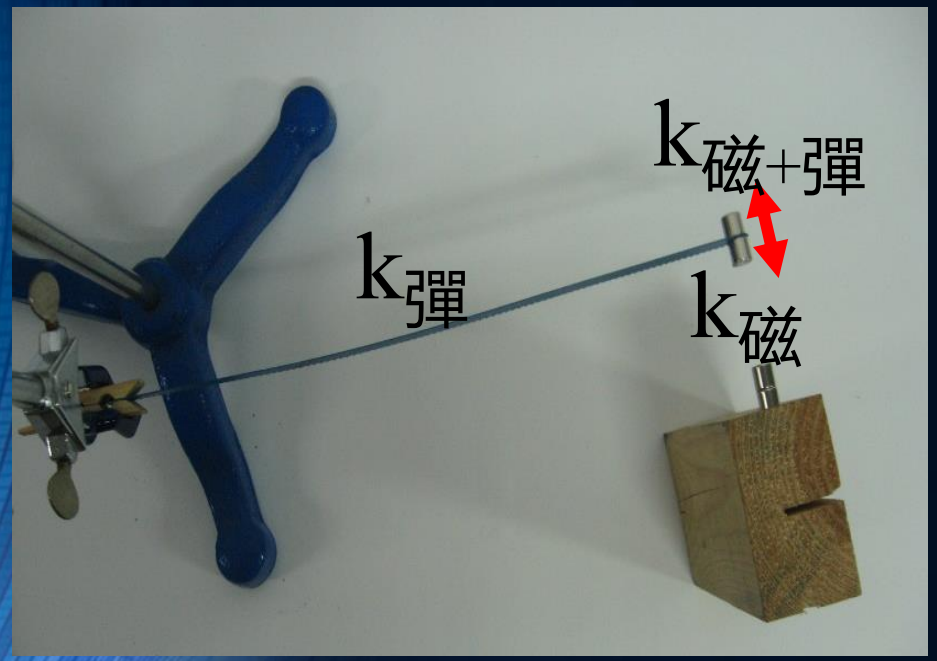


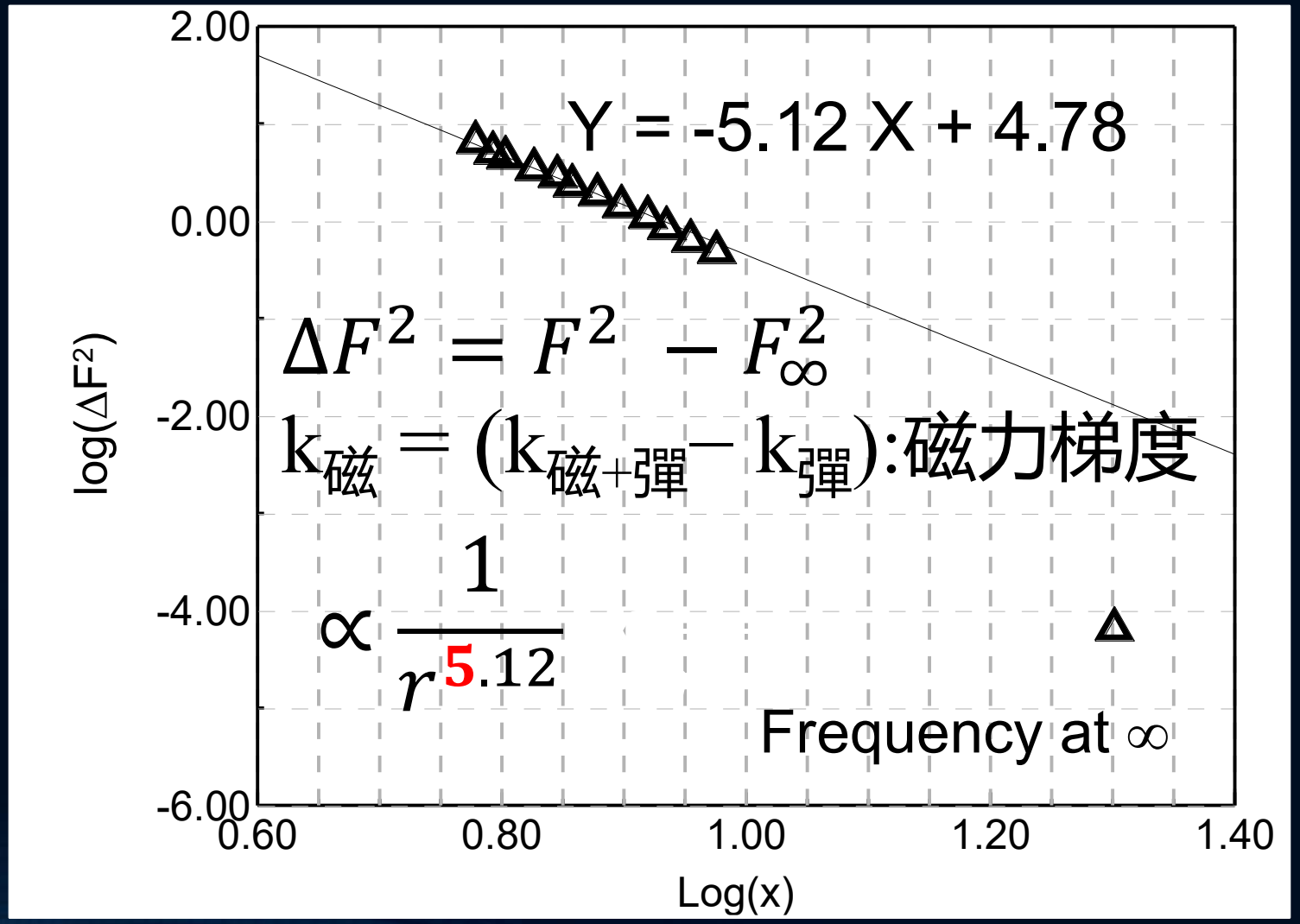
$$\Delta F^2 = F^2 - F_\infty^2$$

$$k_{磁} = k_{磁+彈} - k_{彈}$$

四、磁場特性：數據與建模

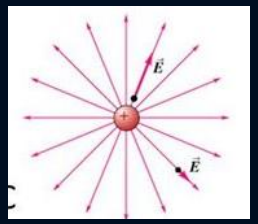
◎動態模式





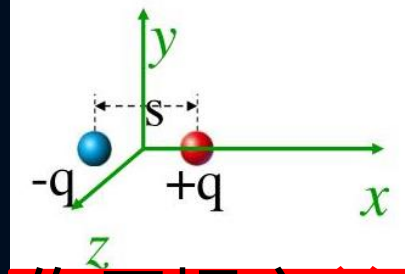
減輕負荷: 先討論電荷之間的作用，再轉借應用

◎單極場$\propto \frac{1}{r^2}$



◎偶極場$\propto \frac{d}{dr}\frac{1}{r^2} \propto \frac{1}{r^3}$

Dipole: for r>>s : $\vec{E} = \left\langle \frac{1}{4\pi\varepsilon_0}\frac{2qs}{r^3}, 0, 0 \right\rangle$ at <r,0,0>



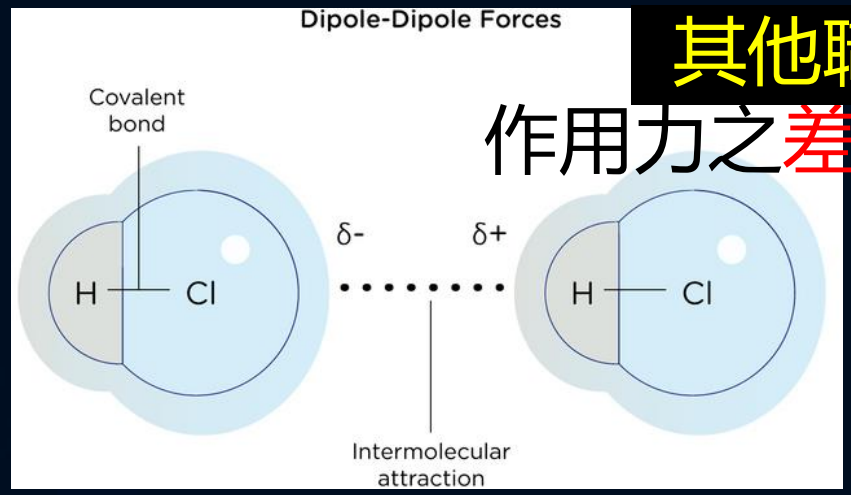
減輕負荷:
其他位置資訊
先遮蔽

作用場之差:

◎偶極-偶極力$\propto \frac{d}{dr}\frac{1}{r^3} \propto \frac{1}{r^4}$

其他職場情境

作用力之差



$F = -kr, k = \frac{d}{dr}$ |F|=力梯度

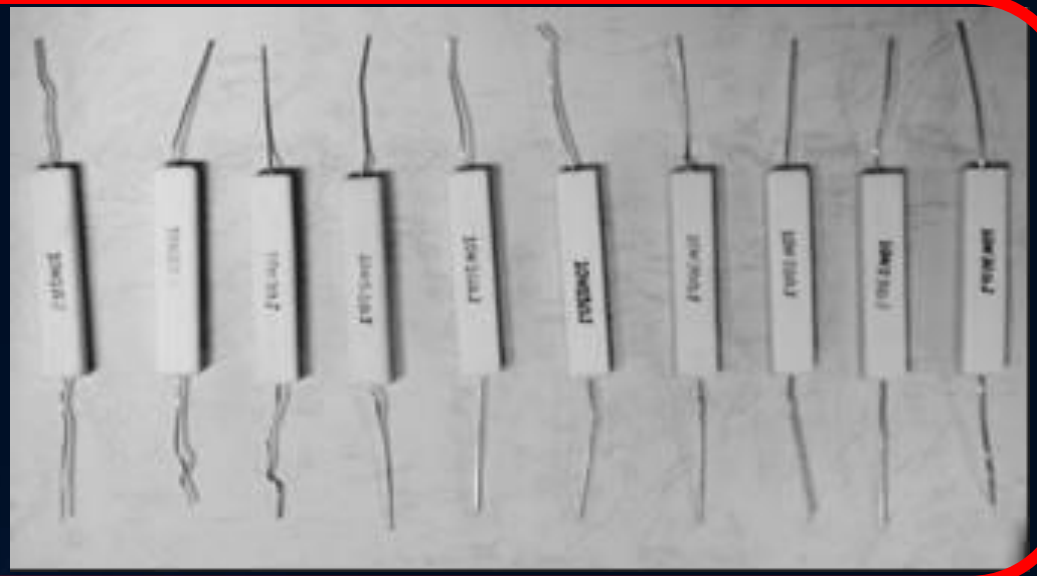
◎偶極-偶極力梯度$\propto \frac{d}{dr}\frac{1}{r^4} \propto \frac{1}{r^5} \rightarrow k_{磁} \propto \frac{1}{r^5}$

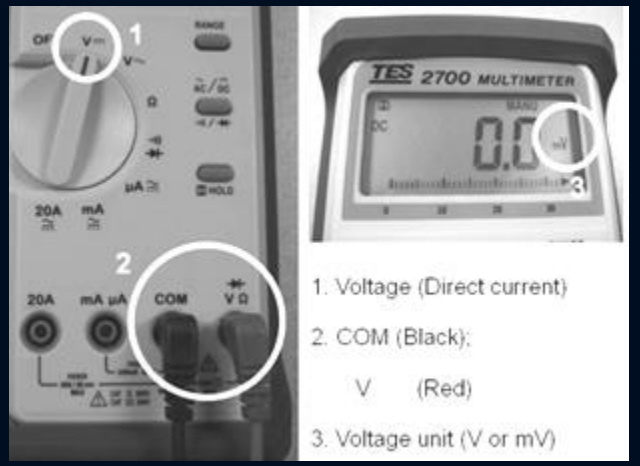
熱學實驗(國中科學奧林匹亞2007)
4th International Junior Science Olympiad

實驗題:
白熾燈(鎢絲燈)的能量轉換
(黑體輻射)

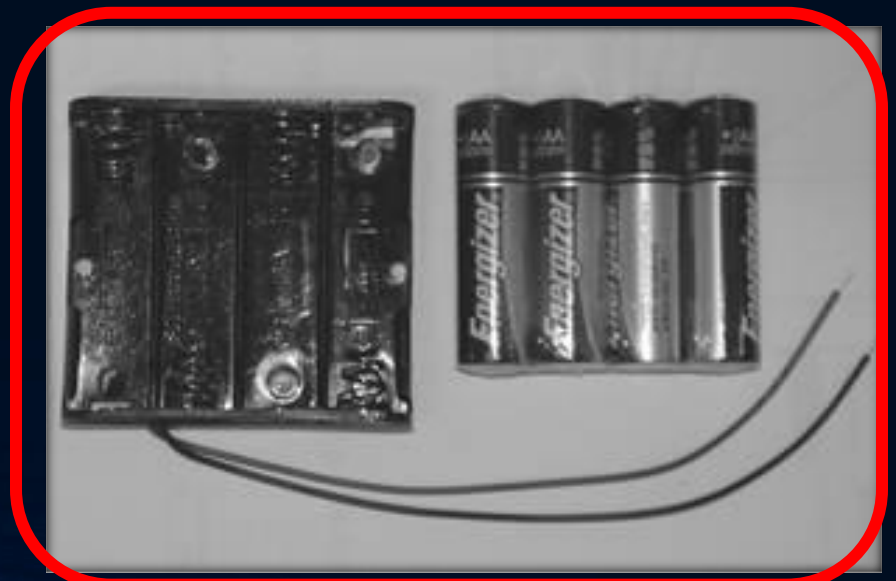
Practical Examination:
Part IV:
Energy Transfer Associated with an Incandescent Lamp
(Black-Body Radiation)

減輕負荷的器材:





可宣布室海
不用給一人一支

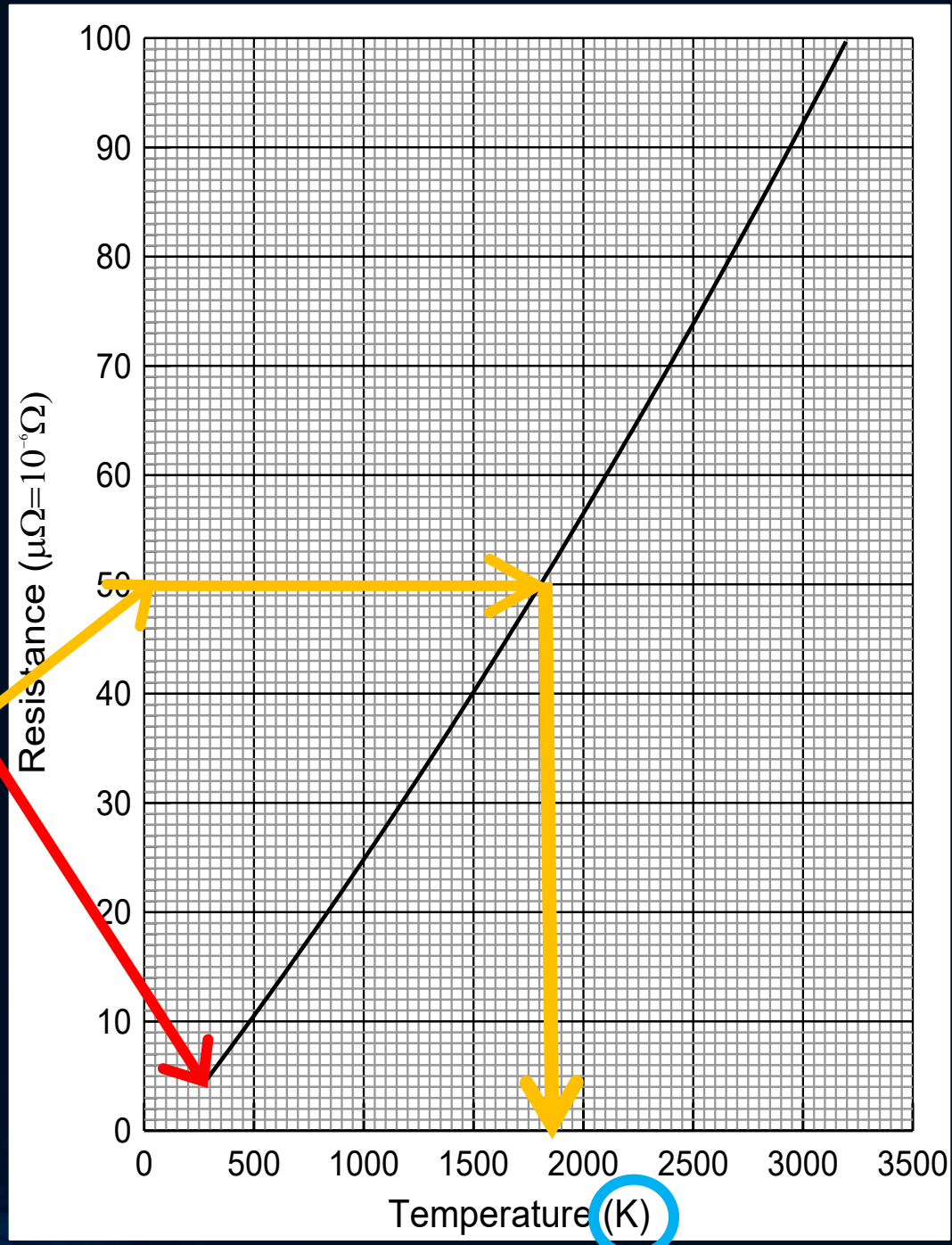


鎢絲電阻率$\rho(T)$

測燈絲$R \rightarrow T$

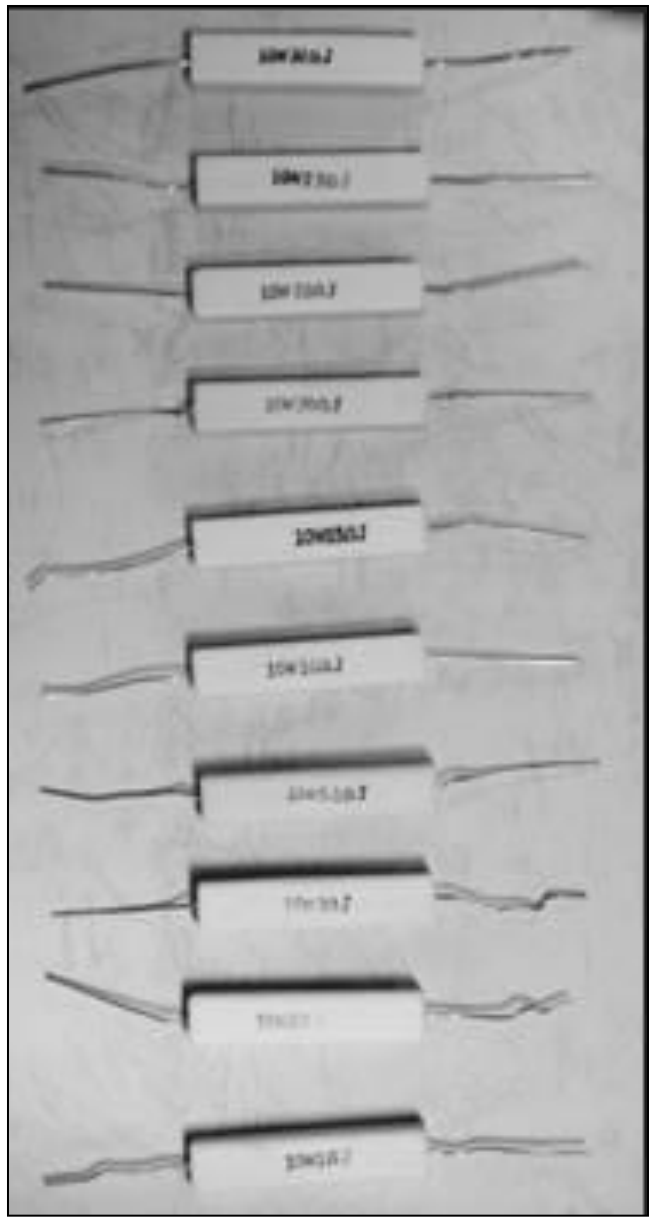
減輕操作負荷(**先不發電池**):

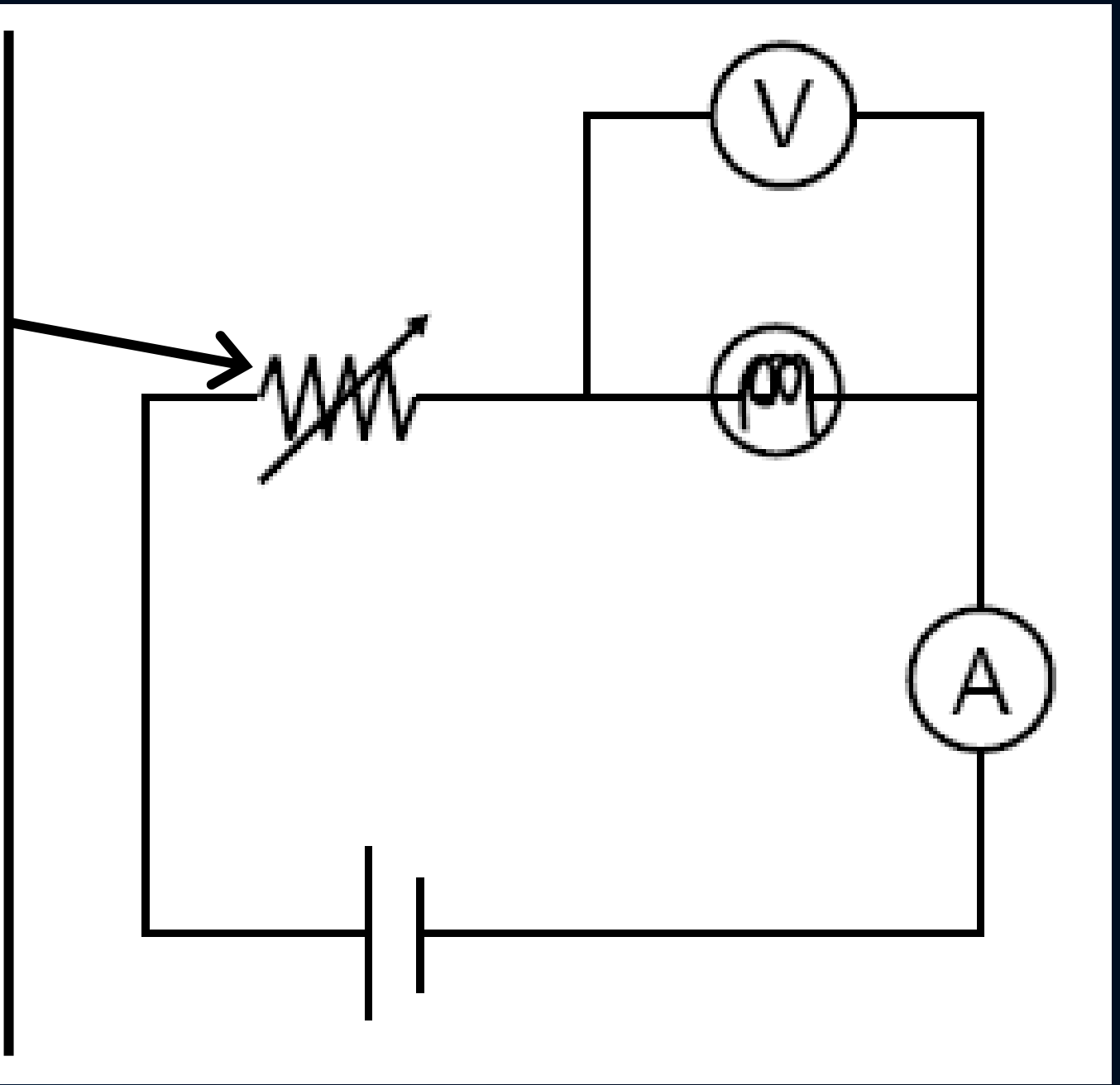
1. 宣布攝氏**室溫**:
   換算**絕對溫度**並記錄。
2. **先**三用電表，測燈絲**室溫電阻**。
3. **然後才**發給電池。
4. 測量I-V，計算V/I=**R→R**



電路：

組合水泥電阻，測I與V



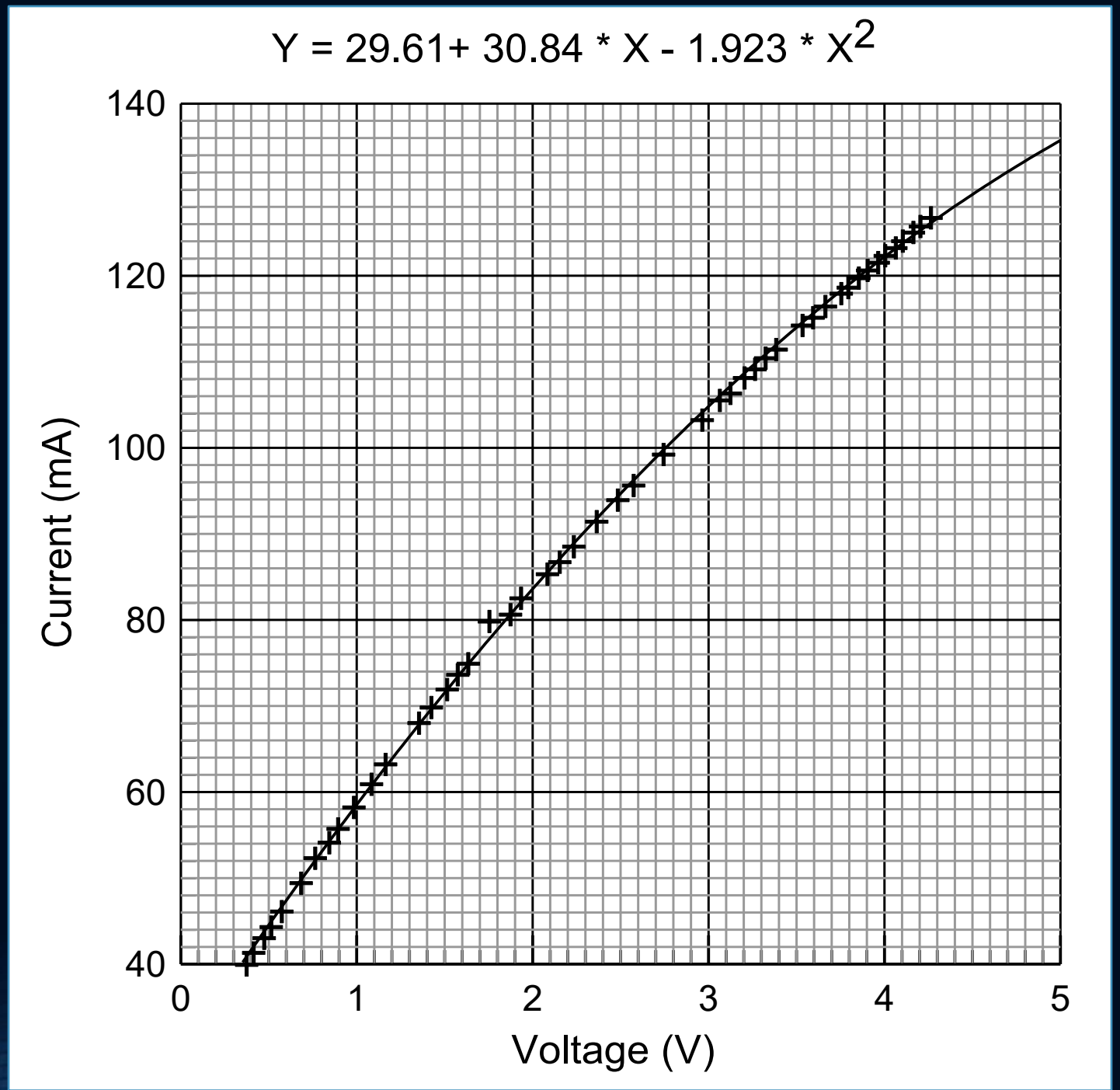


數據

	I	V	R → T	P=IV	log(T)	Log (P)
1	126.8	4.26	33.60	1451.52	540.17	3.16	2.73
2	125.8	4.2	33.39	1443.84	528.36	3.16	2.72
3	125.1	4.16	33.25	1438.98	520.42	3.16	2.72
4	124.1	4.1	33.04	1431.08	508.81	3.16	2.71
5	123.3	4.06	32.93	1427.04	500.60	3.15	2.70
6	122.4	4	32.68	1417.92	489.60	3.15	2.69
7	121.6	3.96	32.57	1413.73	481.54	3.15	2.68
8	120.7	3.9	32.31	1404.37	470.73	3.15	2.67
9	119.8	3.85	32.14	1397.94	461.23	3.15	2.66
10	118.7	3.79	31.93	1390.27	449.87	3.14	2.65
11	118	3.75	31.78	1384.75	442.50	3.14	2.65
12	116.5	3.66	31.42	1371.30	426.39	3.14	2.63
13	115.2	3.59	31.16	1361.92	413.57	3.13	2.62
14	114.3	3.53	30.88	1351.54	403.48	3.13	2.61
15	111.5	3.38	30.31	1330.33	376.87	3.12	2.58
16	110.5	3.32	30.05	1320.31	366.86	3.12	2.56
17	109.2	3.26	29.85	1313.14	355.99	3.12	2.55
18	108.2	3.2	29.57	1302.71	346.24	3.11	2.54
19	106.4	3.12	29.32	1293.28	331.97	3.11	2.52
20	105.6	3.06	28.98	1280.29	323.14	3.11	2.51
21	103.3	2.96	28.65	1268.14	305.77	3.10	2.49
22	99.3	2.74	27.59	1228.05	272.08	3.09	2.43
23	95.7	2.57	26.85	1200.00	245.95	3.08	2.39
24	94	2.48	26.38	1182.02	233.12	3.07	2.37

	I	V	R → T	P=IV	log(T)	Log (P)
25	91.5	2.36	25.79	1159.44	215.94	3.06	2.33
26	88.6	2.23	25.17	1135.53	197.58	3.06	2.30
27	86.8	2.15	24.77	1120.15	186.62	3.05	2.27
28	85.4	2.08	24.36	1104.19	177.63	3.04	2.25
29	82.6	1.93	23.37	1065.83	159.42	3.03	2.20
30	80.7	1.87	23.17	1058.31	150.91	3.02	2.18
31	79.9	1.75	21.90	1008.75	139.83	3.00	2.15
32	75	1.63	21.73	1002.12	122.25	3.00	2.09
33	73.7	1.57	21.30	985.21	115.71	2.99	2.06
34	72	1.51	20.97	972.21	108.72	2.99	2.04
35	69.9	1.42	20.31	946.27	99.26	2.98	2.00
36	68.1	1.35	19.82	926.84	91.94	2.97	1.96
37	63.3	1.16	18.33	867.19	73.43	2.94	1.87
38	61	1.08	17.70	842.34	65.88	2.93	1.82
39	58.3	0.98	16.81	806.34	57.13	2.91	1.76
40	55.8	0.89	15.95	771.59	49.66	2.89	1.70
41	54.2	0.84	15.50	753.27	45.53	2.88	1.66
42	52.4	0.76	14.50	712.78	39.82	2.85	1.60
43	49.5	0.68	13.74	681.42	33.66	2.83	1.53
44	46.2	0.57	12.34	623.81	26.33	2.80	1.42
45	44.4	0.51	11.49	588.56	22.64	2.77	1.35
46	43.1	0.47	10.90	564.38	20.26	2.75	1.31
47	41.4	0.41	9.90	522.57	16.97	2.72	1.23
48	40	0.37	9.25	495.17	14.80	2.69	1.17

I-V

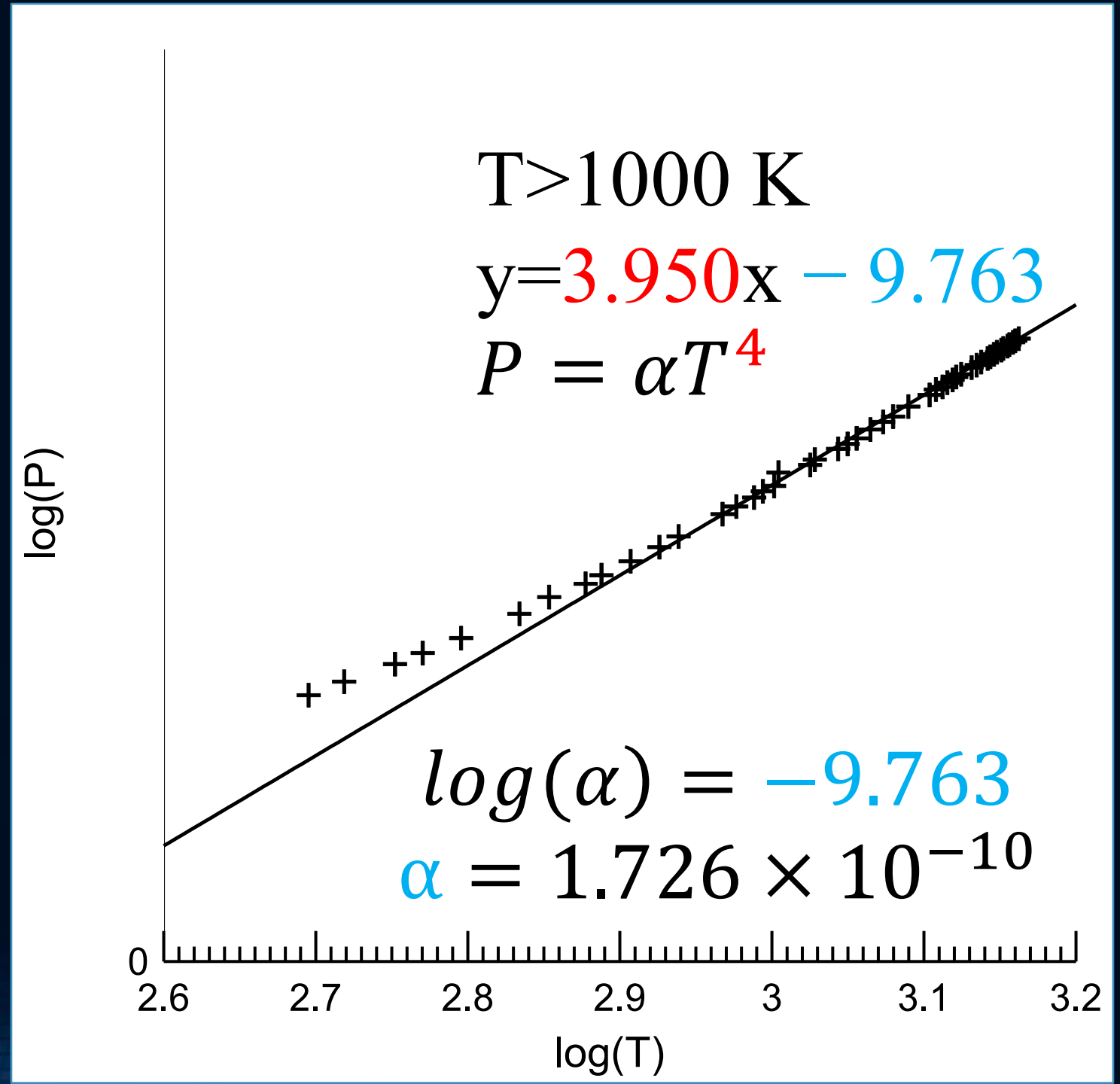

Y = 29.61+ 30.84 * X - 1.923 * X2
140
120
100
80
60
40
Current (mA)
0
1
2
3
4
5
Voltage (V)

log(P)-log(T)

已知高溫時，燈絲輻射功率P與溫度T的關係為

$$P = C(T - T_E) + \alpha T^{\beta}$$

從實驗數據決定α與β。



分析與建模:

熱燈絲的電功率可經由三種方式移轉給週遭環境傳播：

(I)傳導，　　(II)對流，　　(III)輻射。

$P_{CD} \propto \Delta T$,　　$P_{CV} \propto \Delta T$,　　$P_{RD} \propto T^4$

$\propto (T_F - T_E)$,　　$\propto (T_F - T_E)$,

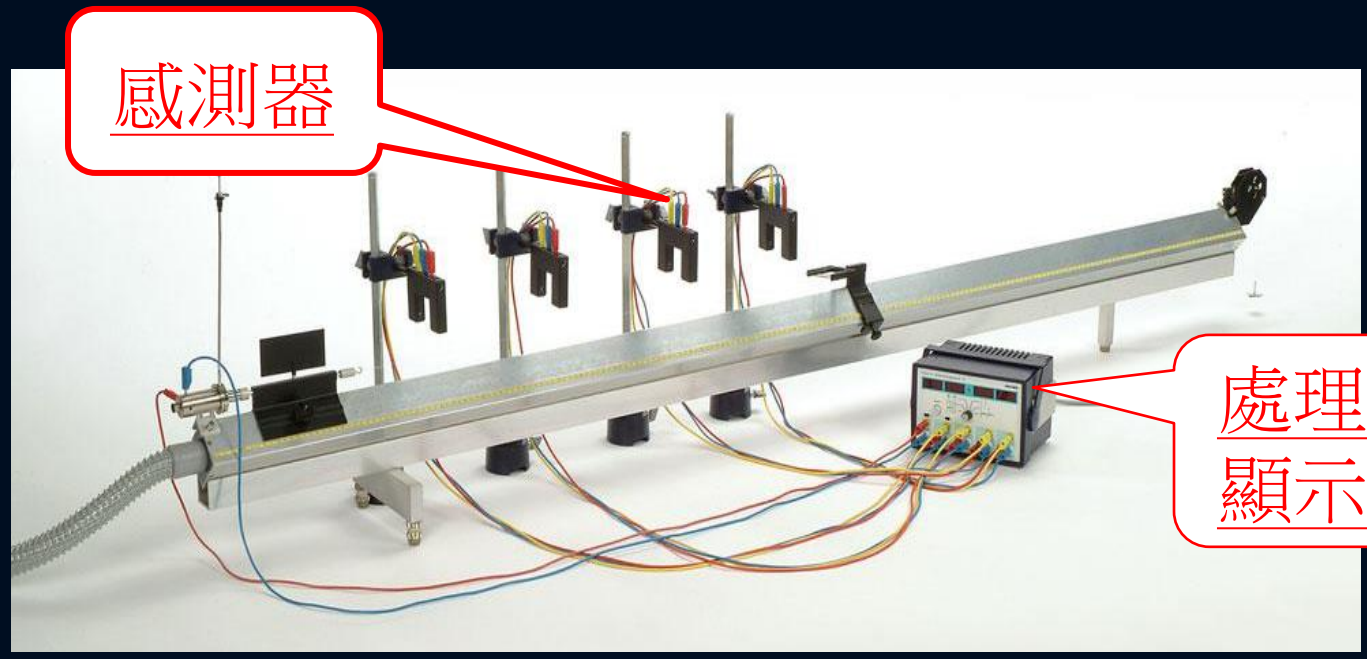
善用DIY、Maker與open source 的資源

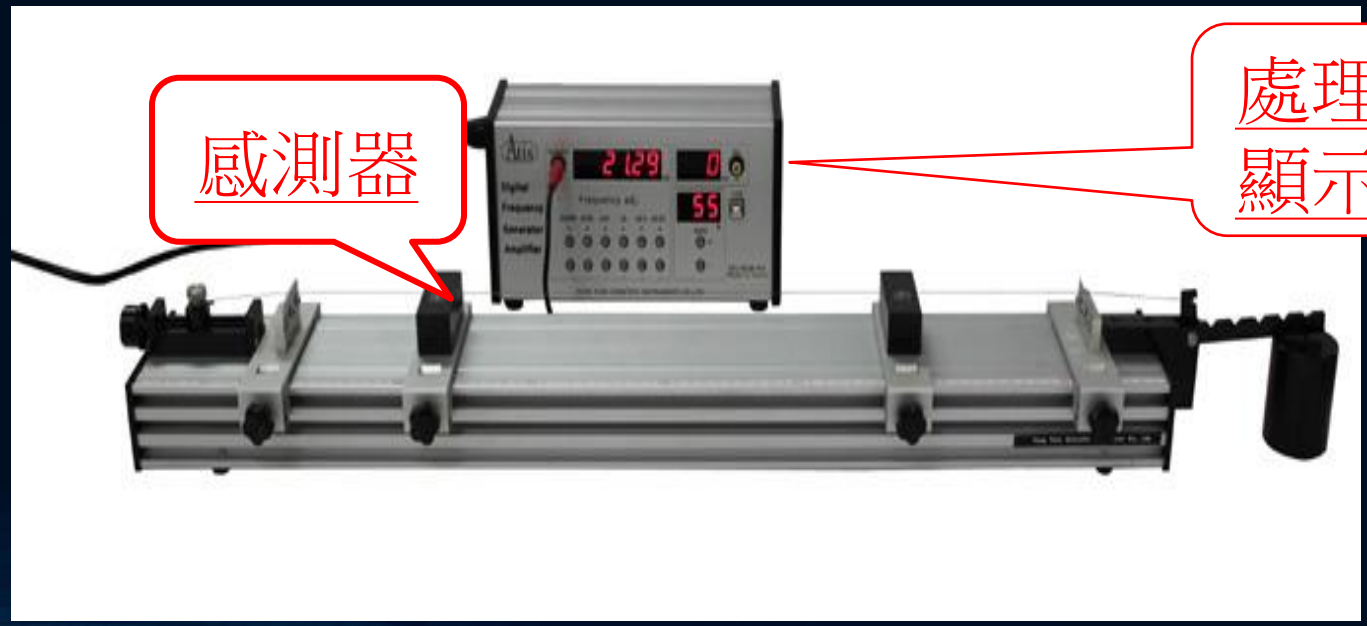
親子天下　2014/7/1出刊

Interaction Design Institute Ivrea,: Arduino

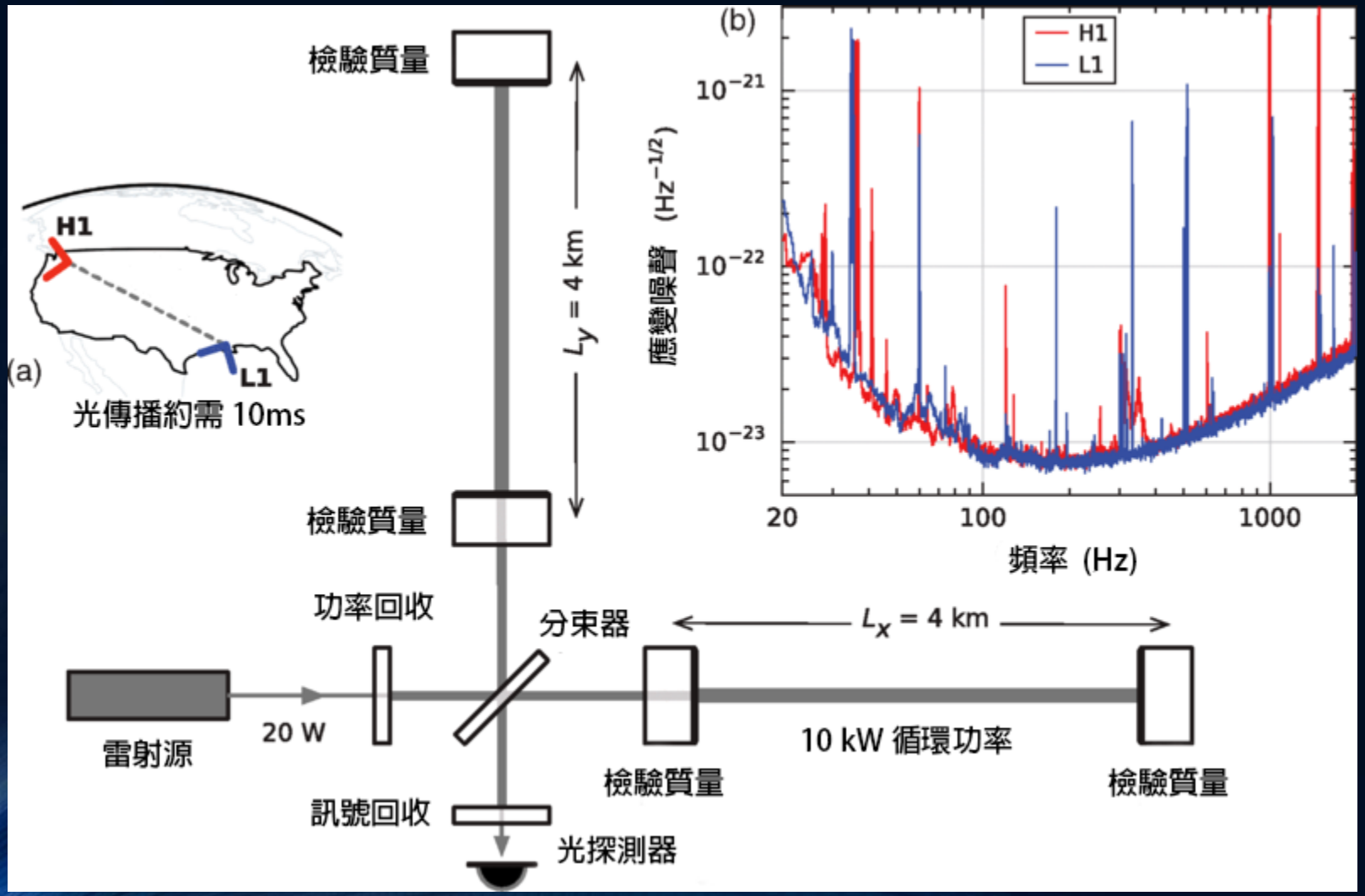
緣起之一

開源與永續經營:
處理器 Arduino...
顯示器
感測器
重複使用
維修更新容易





重力波偵測(訊號!!)裝置(LIGO)，The 2017 Nobel Prize in Physics



重力波偵測-論文摘要-關鍵字

Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.*[*]
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 21 January 2016; published 11 February 2016)

On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitational-wave signal. The signal sweeps upwards in frequency from 35 to 250 Hz with a peak gravitational-wave strain of 1.0×10^{-21}. It matches the waveform predicted by general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole. The signal was observed with a matched-filter signal-to-noise ratio of 24 and a false alarm rate estimated to be less than 1 event per 203 000 years, equivalent to a significance greater than 5.1σ. The source lies at a luminosity distance of 410^{+160}_{-180} Mpc corresponding to a redshift $z = 0.09^{+0.03}_{-0.04}$. In the source frame, the initial black hole masses are $36^{+5}_{-4} M_{\odot}$ and $29^{+4}_{-4} M_{\odot}$, and the final black hole mass is $62^{+4}_{-4} M_{\odot}$, with $3.0^{+0.5}_{-0.5} M_{\odot} c^2$ radiated in gravitational waves. All uncertainties define 90% credible intervals. These observations demonstrate the existence of binary stellar-mass black hole systems. This is the first direct detection of gravitational waves and the first observation of a binary black hole merger.

重力波(5)、訊號(4)

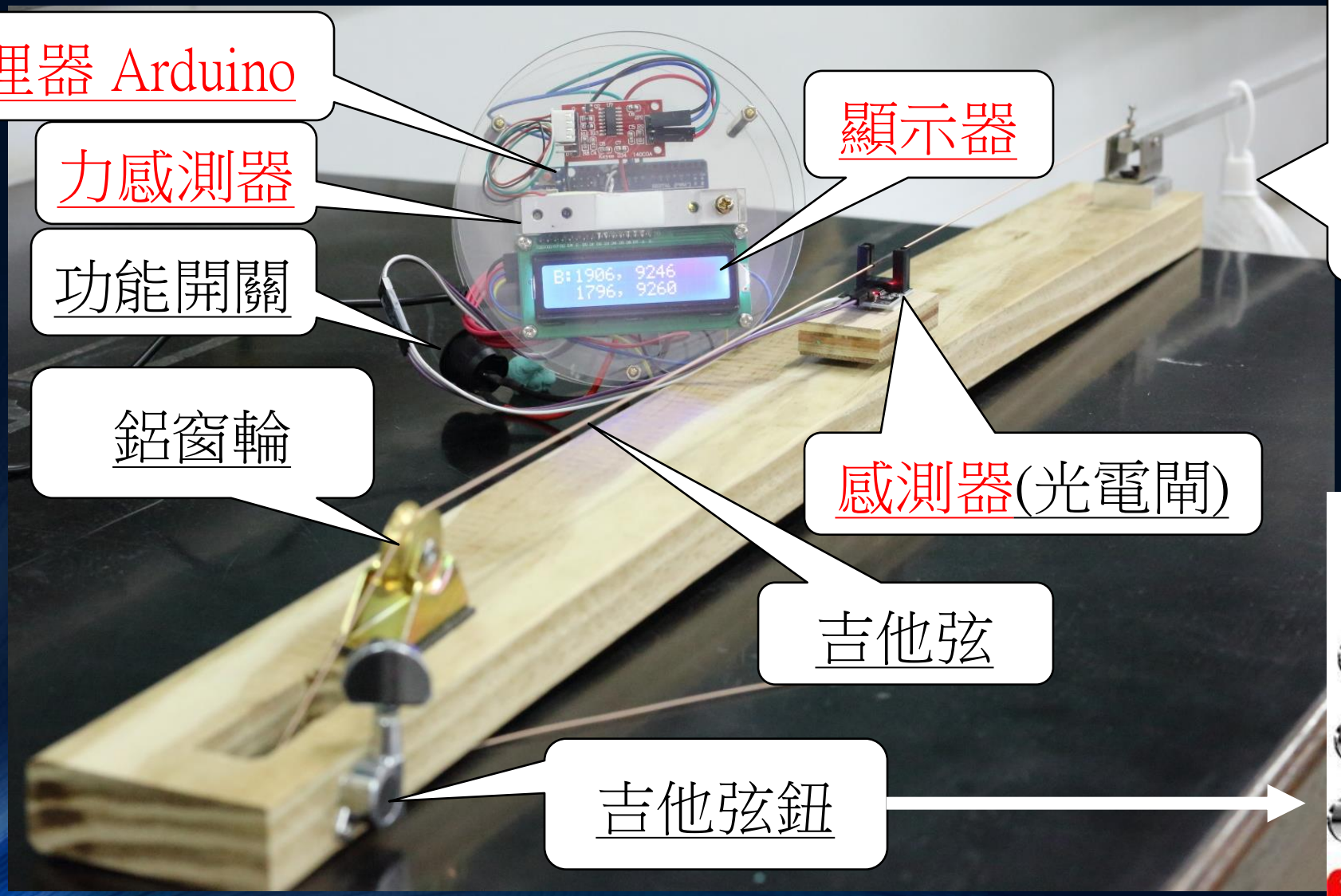
So many Signals

https://youtu.be/evETS8_WFGE?list=PLjH1eozGortCJzthyGt_anVWgTVpmbhSz

She is singing !

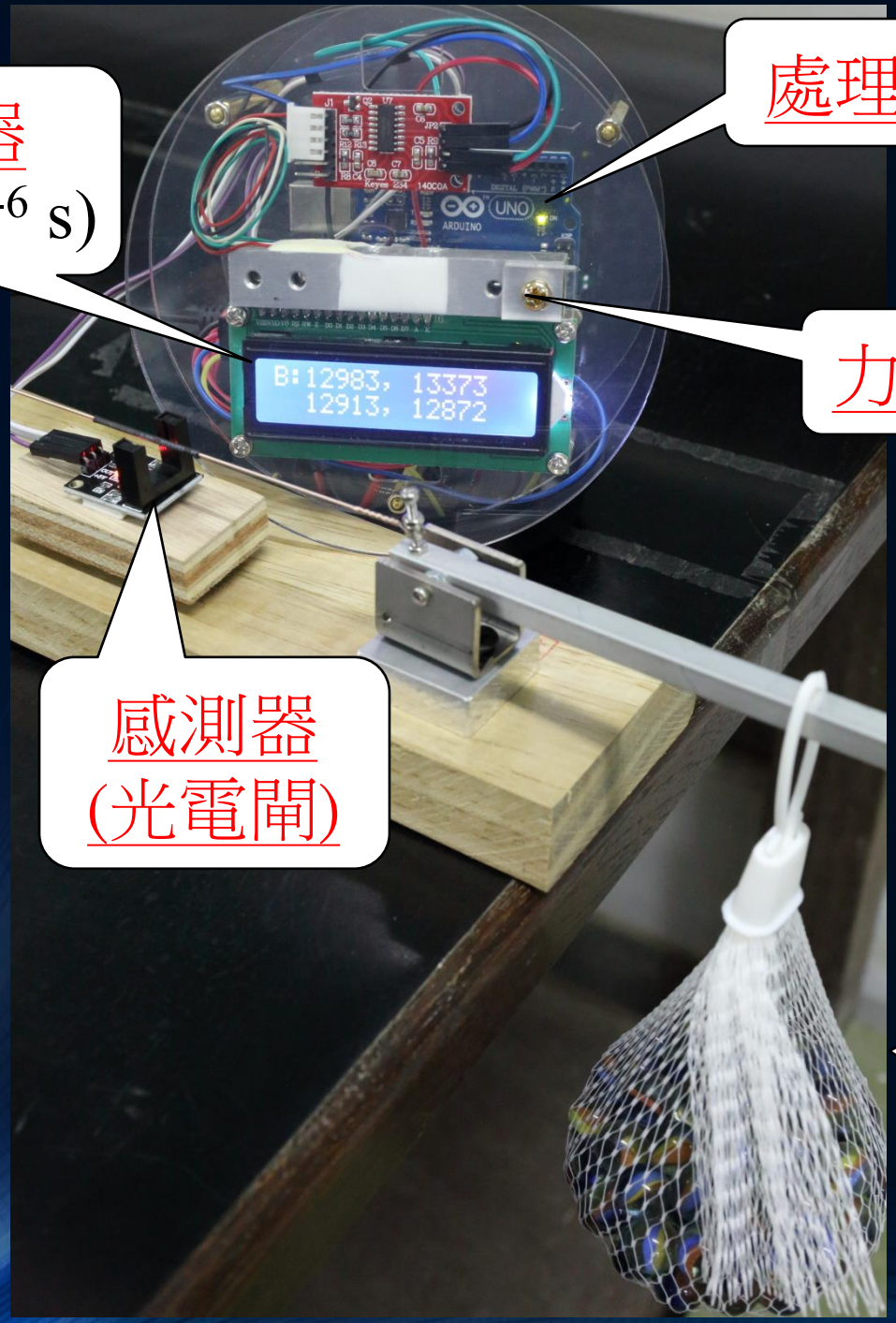
https://youtu.be/evETS8_WFGE?list=PLjH1eozGortCJzthyGt_anVWgTVpmbhSz

力感測實作、弦波實作（單弦吉他）



DIY多功能實作平台

力感測實作、弦波實實作



顯示器
微秒(10^{-6} s)

處理器

力感測器

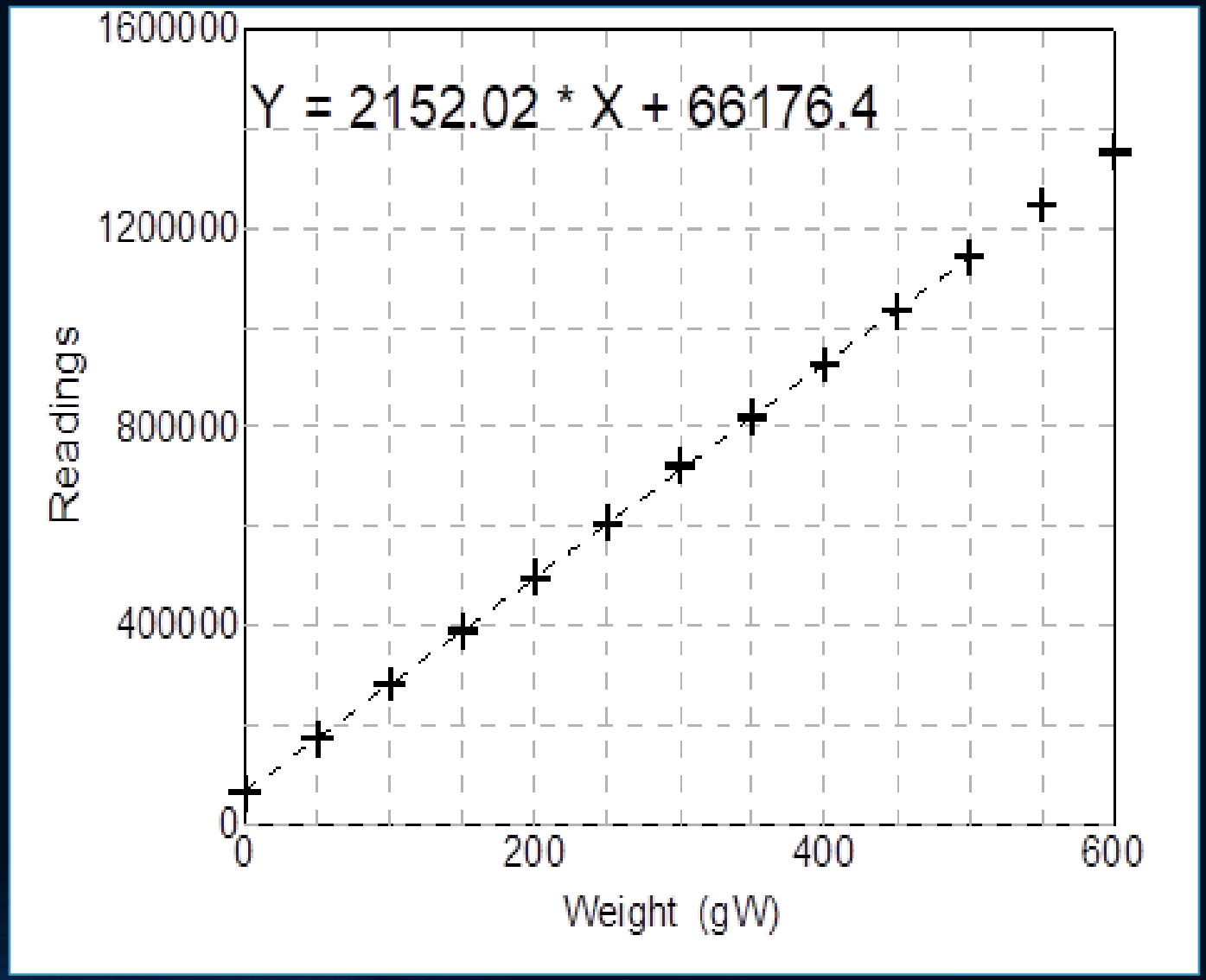
感測器
(光電閘)

下掛彈珠

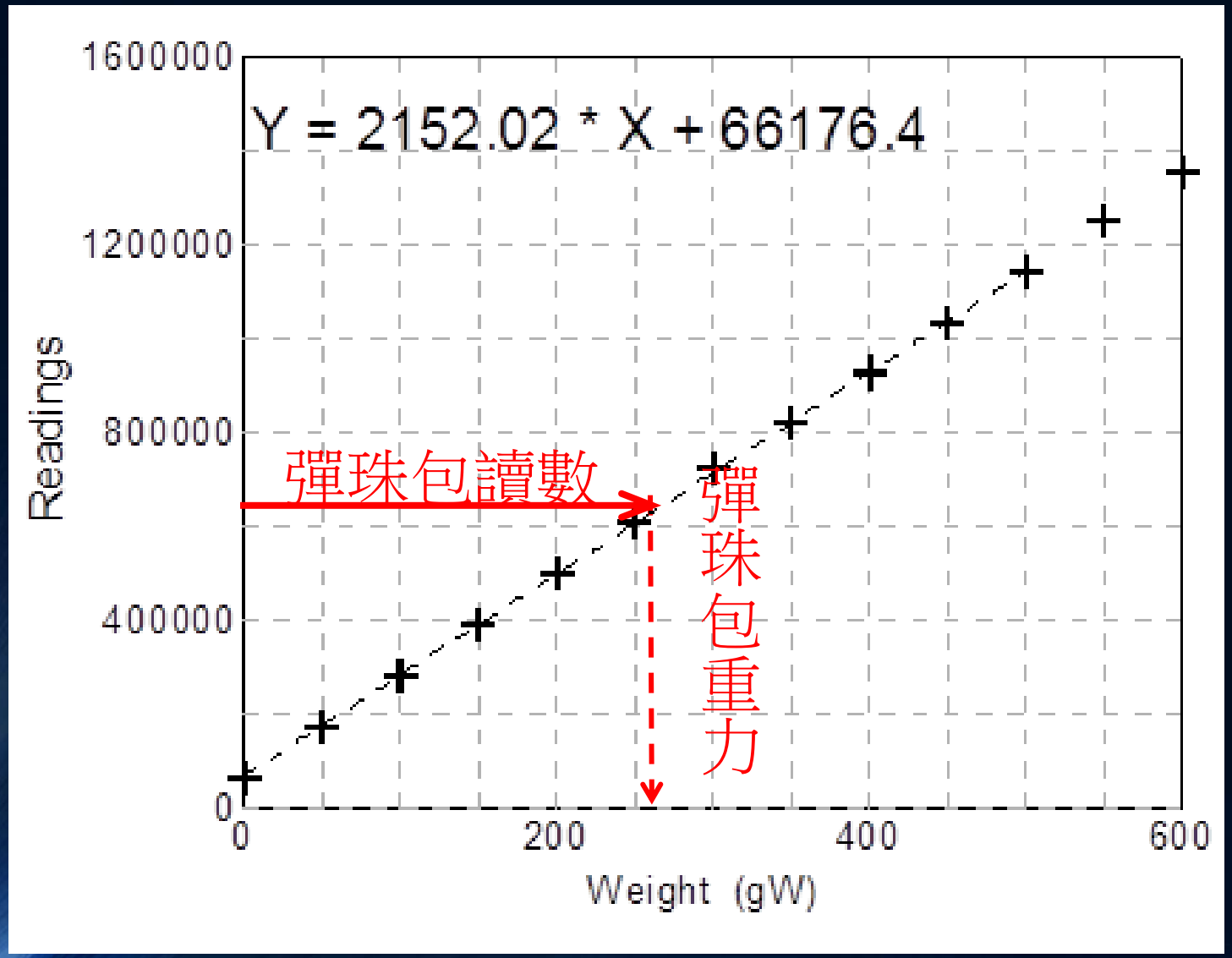
基本測量-用水重量校準力感測器

力感測器校準實作:

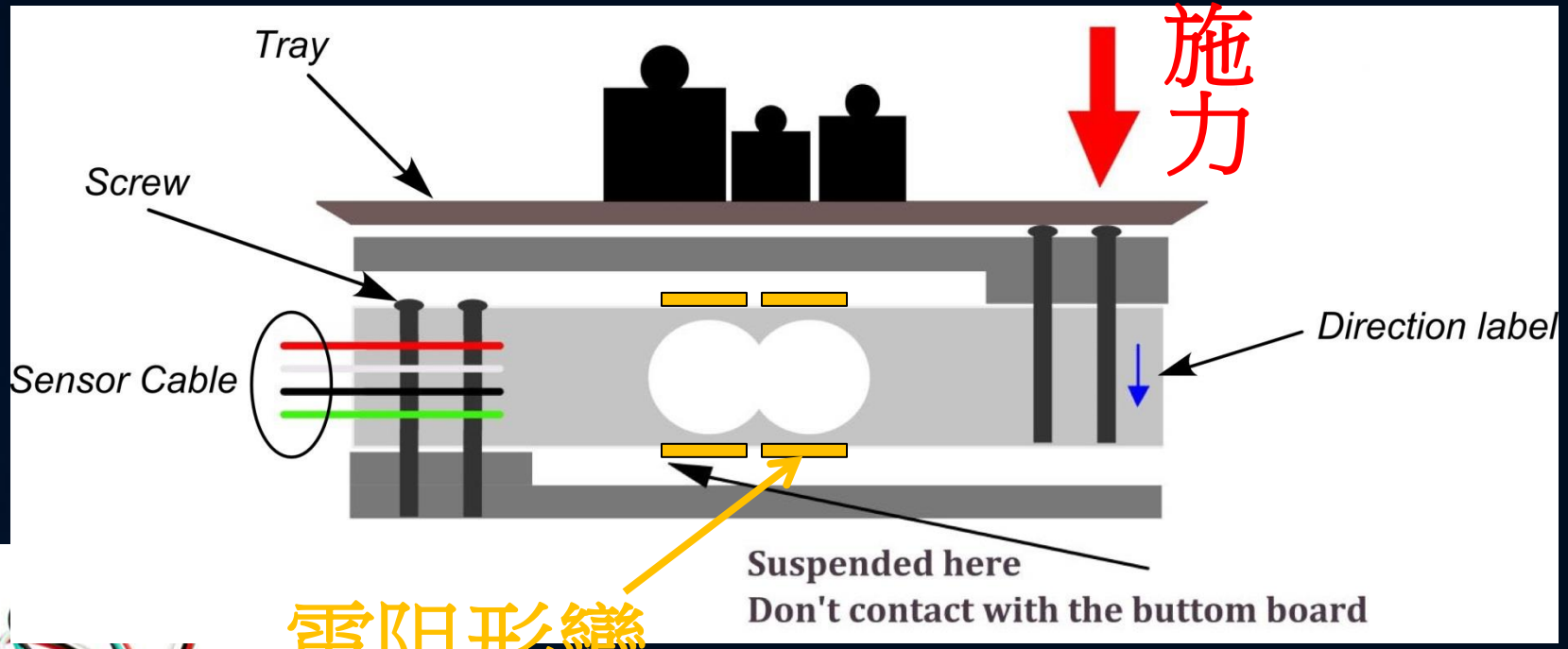
重量（gw）	量力計讀數
0	62200
50	171500
100	282100
150	389500
200	496650
250	605300
300	721500
350	819700
400	925900
450	1034100
500	1142100
550	1248450
600	1354200



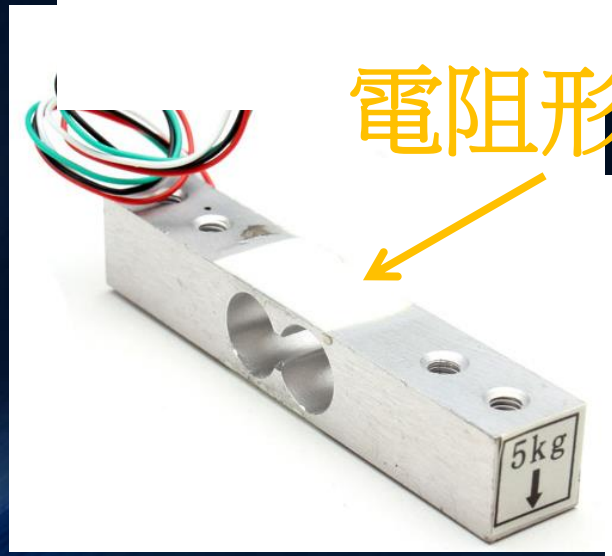
測量彈珠包重量

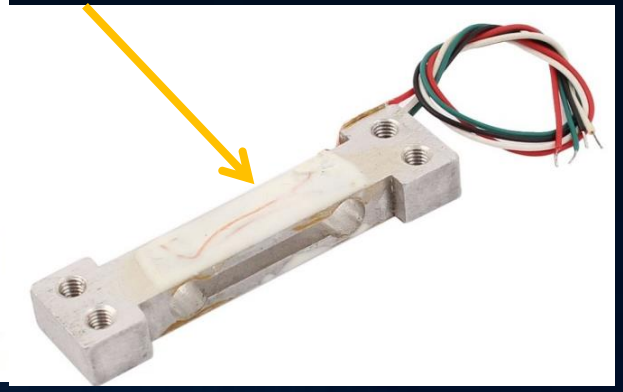

Y = 2152.02 * X + 66176.4
1600000
1200000
800000
400000
0
Readings
0
200
400
600
Weight (gW)
彈珠包讀數
彈珠包重力

力感測器構造


Tray
施力
Screw
Sensor Cable
Direction label
Suspended here
Don't contact with the buttom board

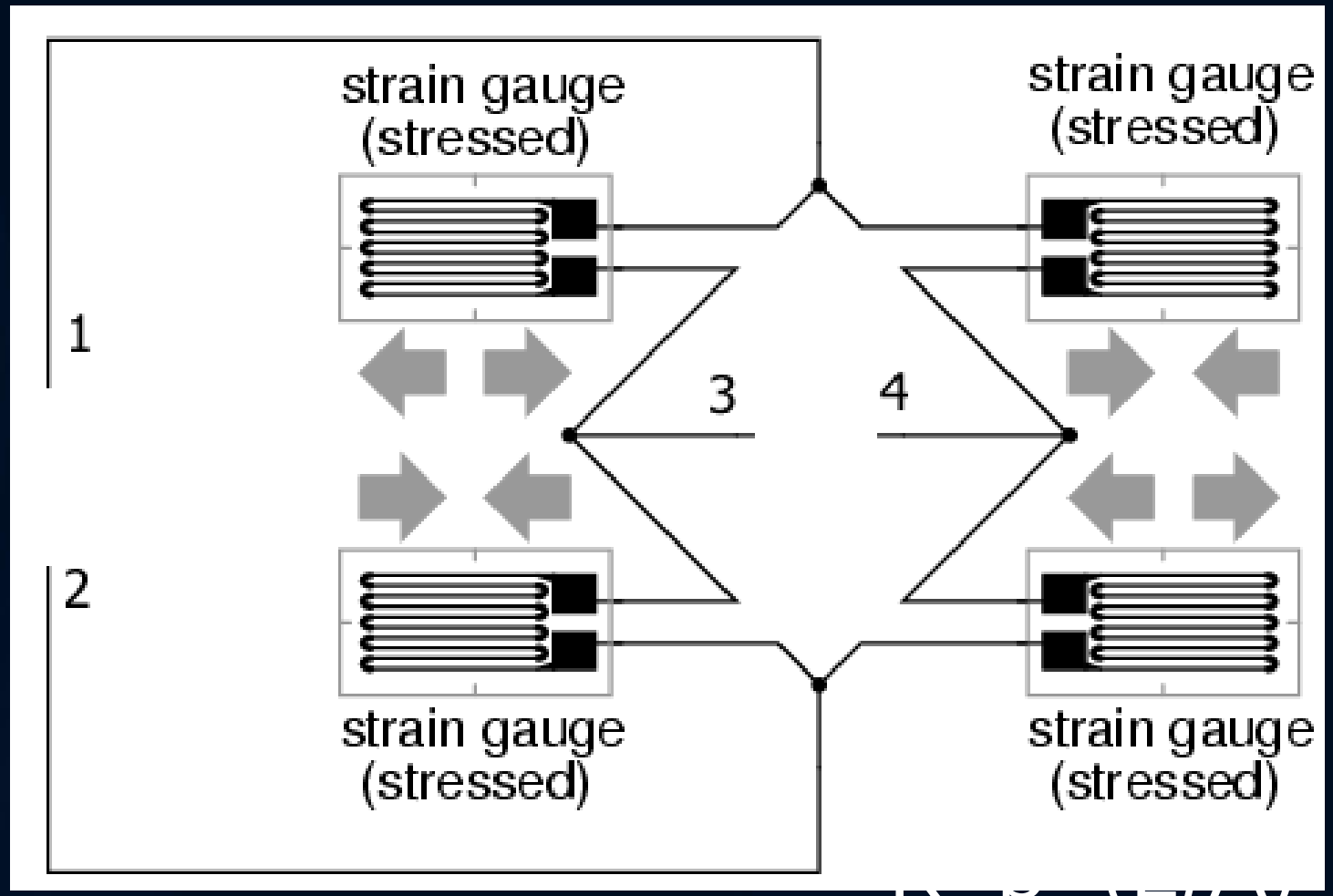
電阻形變


5kg

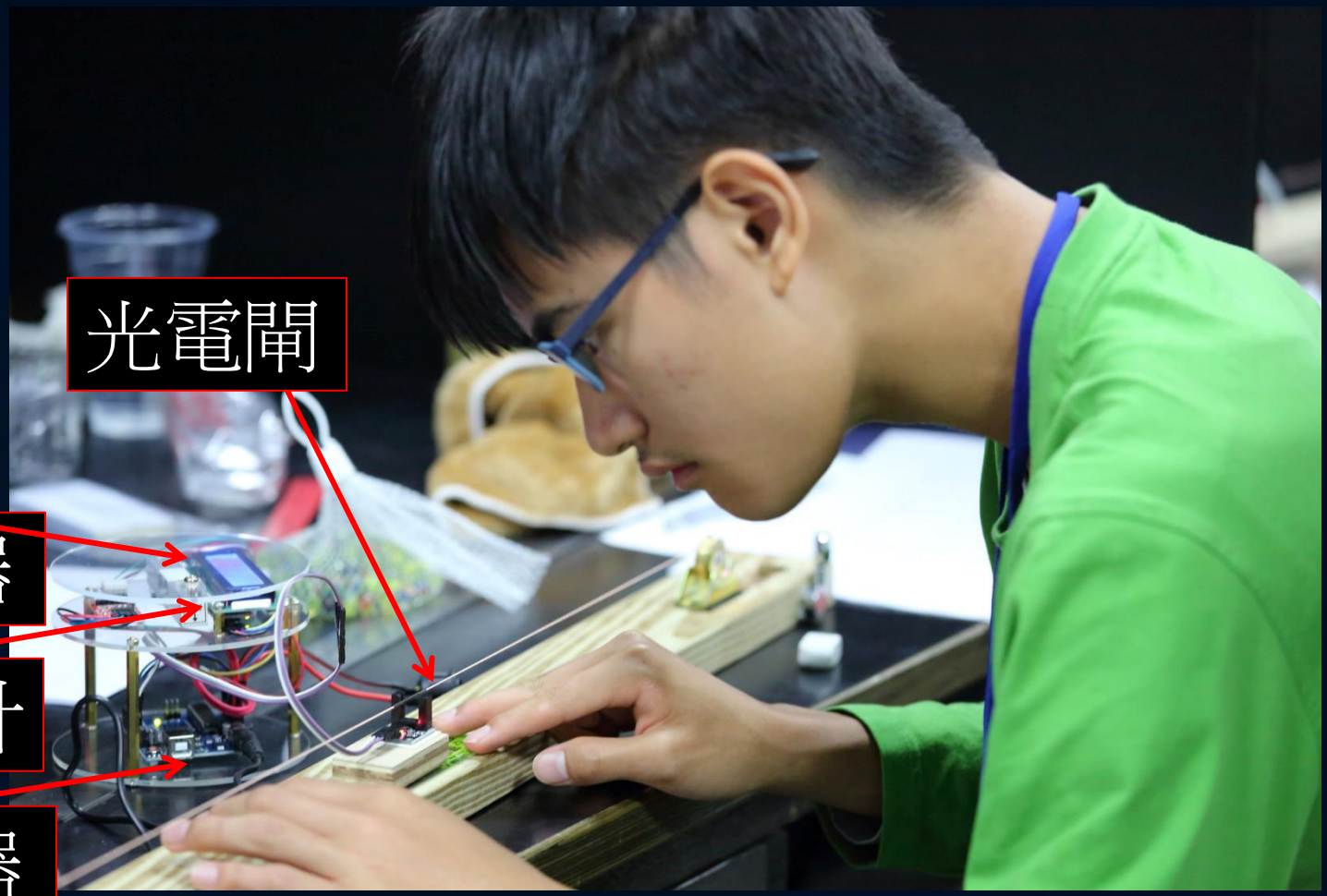



50Kg

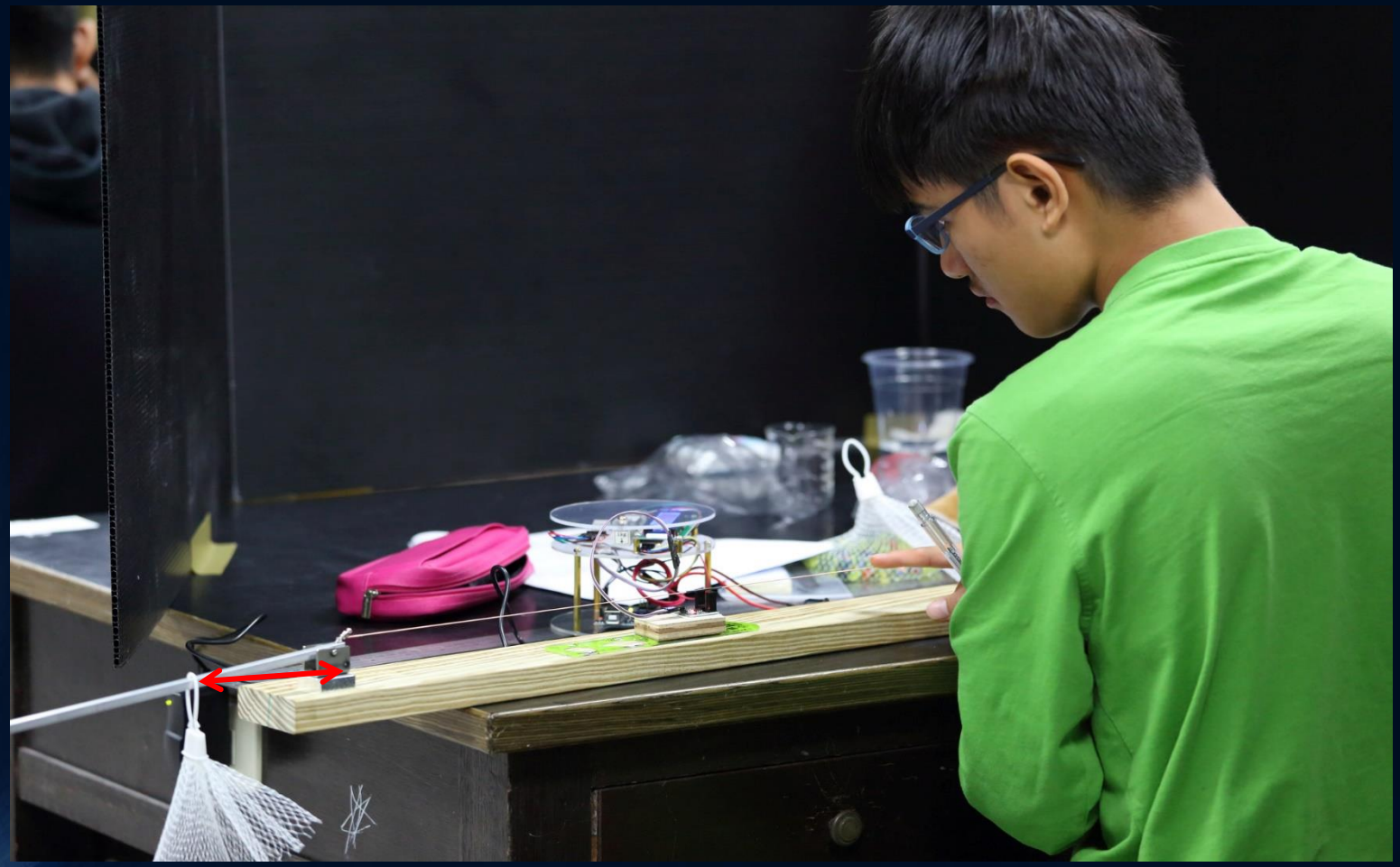
力感測器原理 (電橋應用)


strain gauge
(stressed)
strain gauge
(stressed)
1
3
4
2
strain gauge
(stressed)
strain gauge
(stressed)

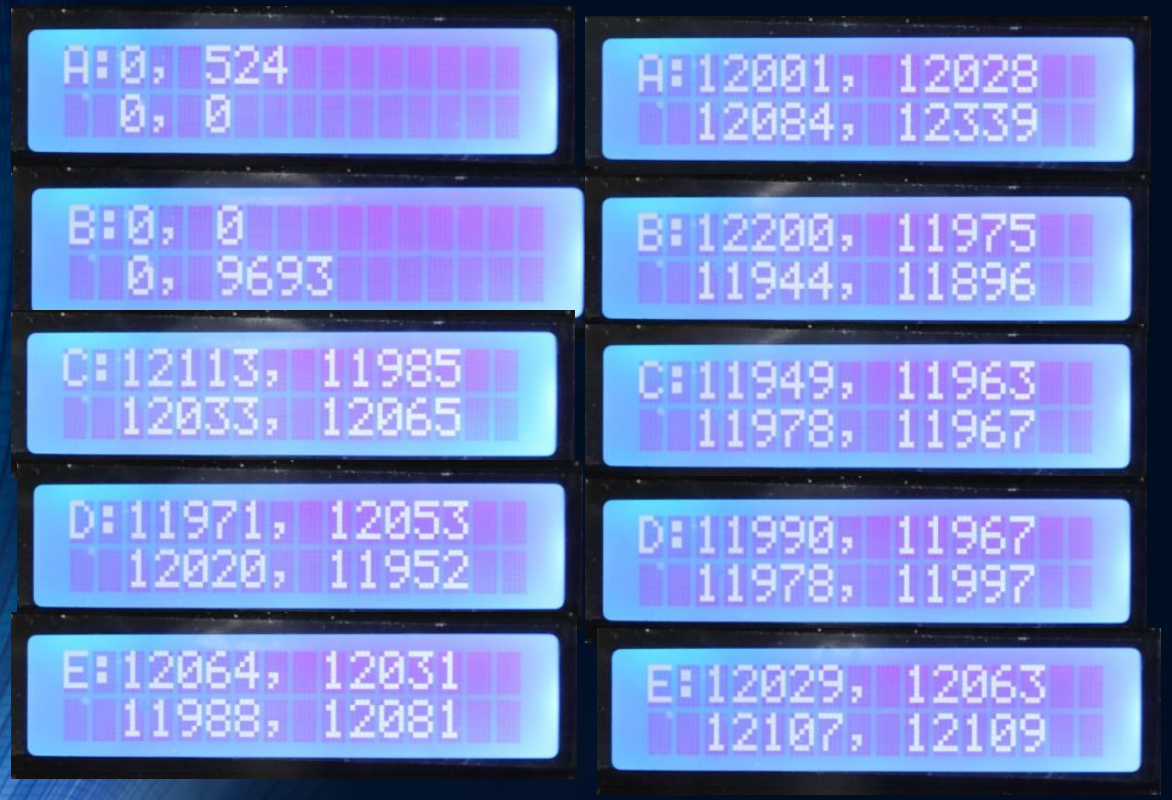
弦波頻率測量



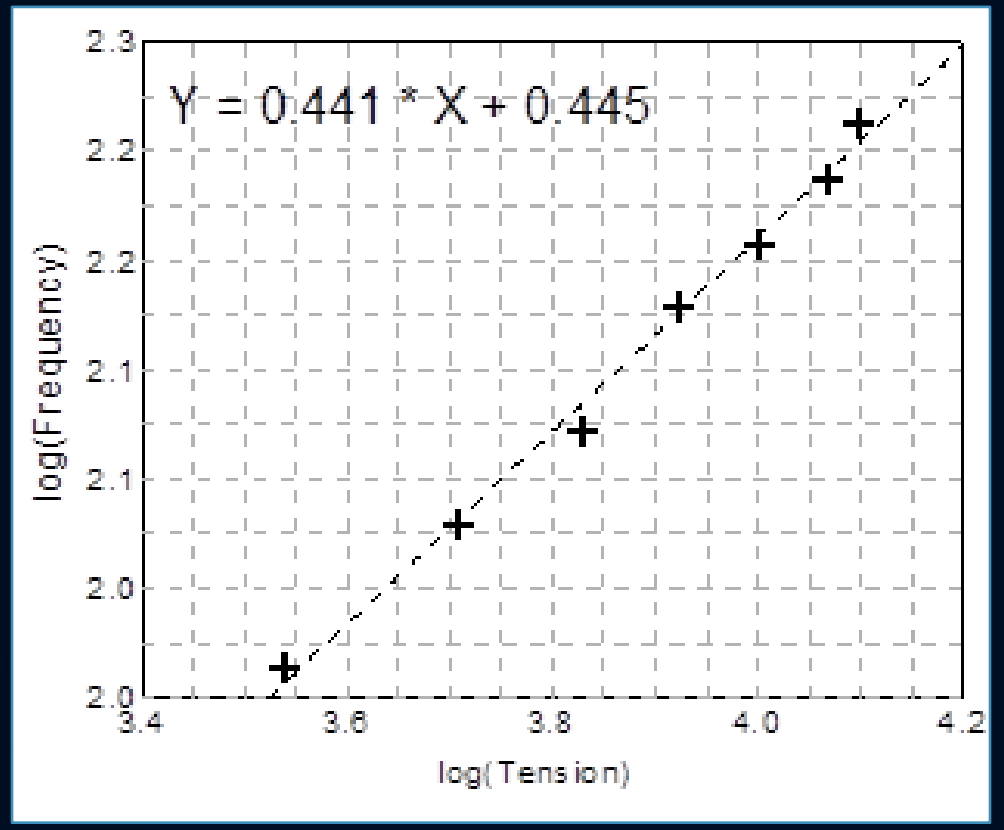
弦波頻率測量



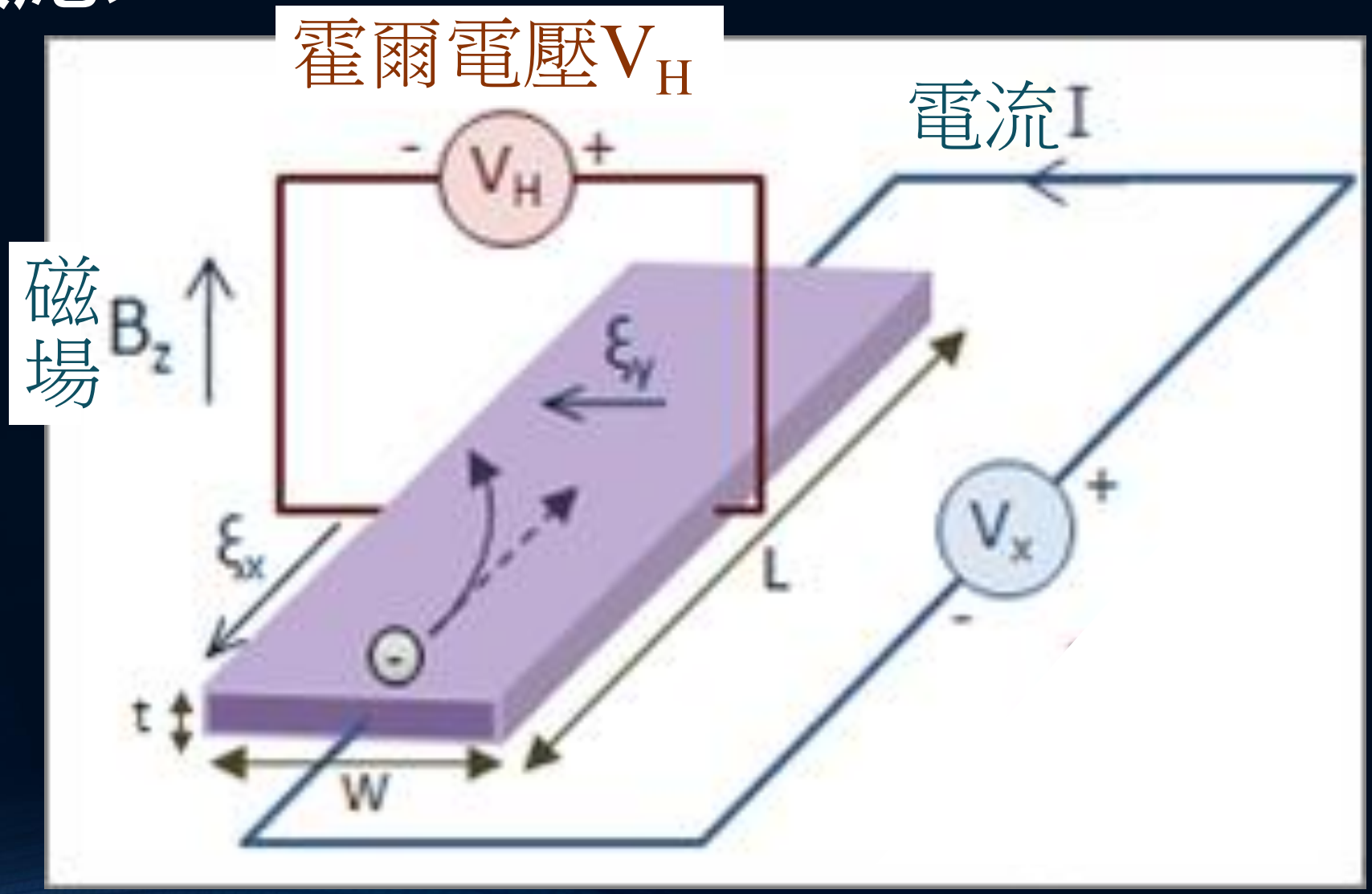
弦波頻率與張力關係探究
數據與建模



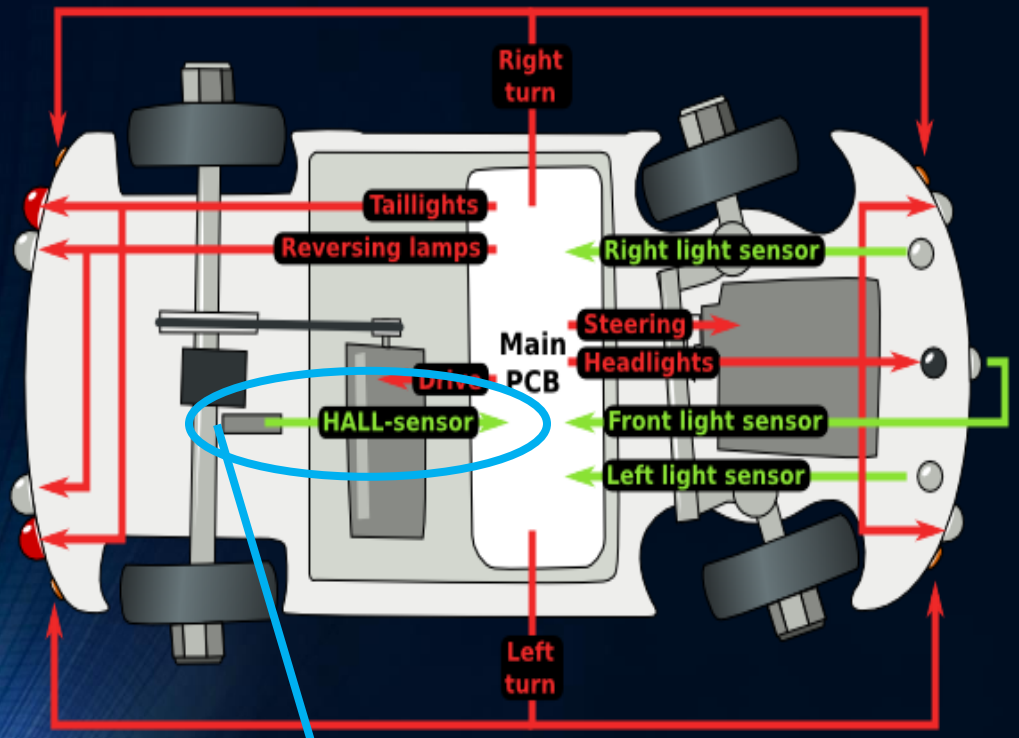
微秒(10^{-6} s)



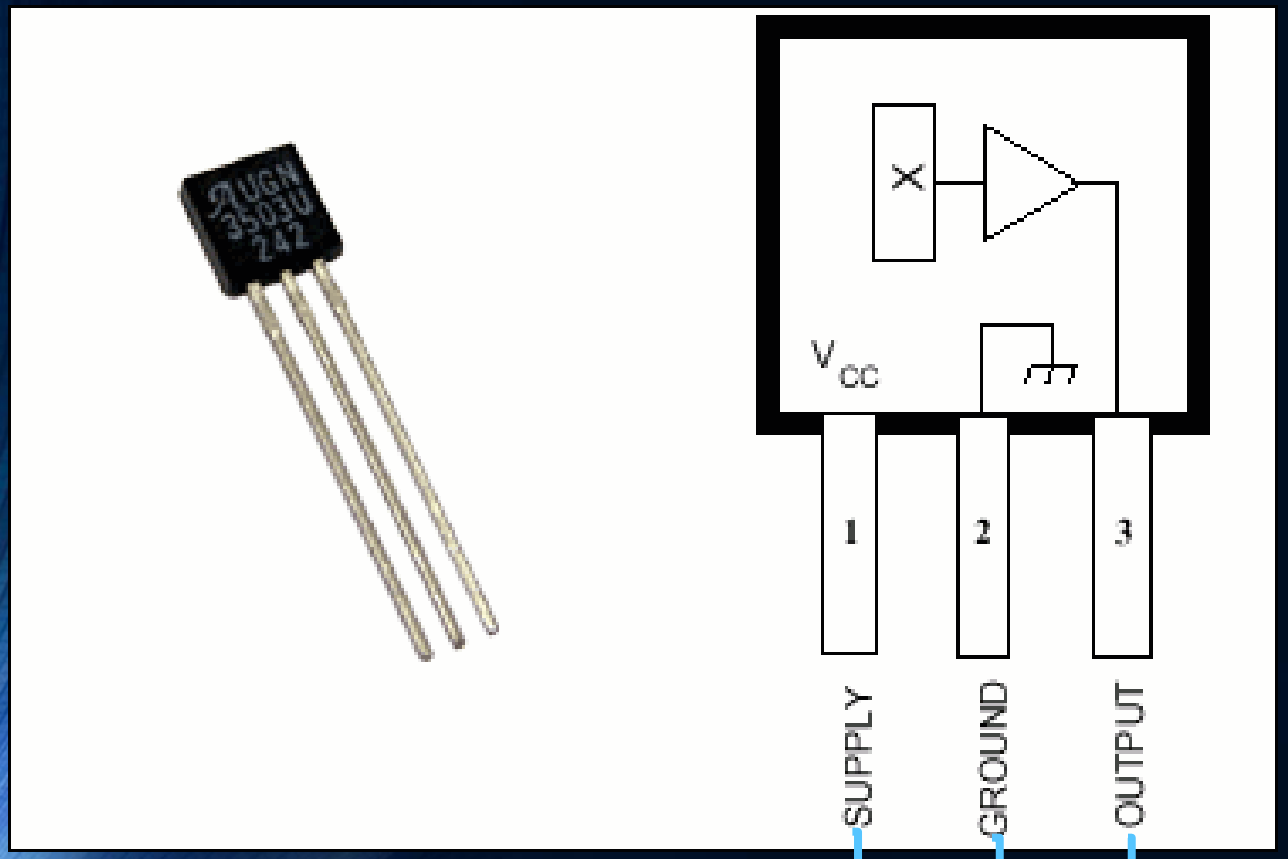
霍爾感測模組
原理：霍爾效應



霍爾感測模組
應用：偵測距離、位移、速度、轉速



霍爾感測模組
選取線性霍爾IC

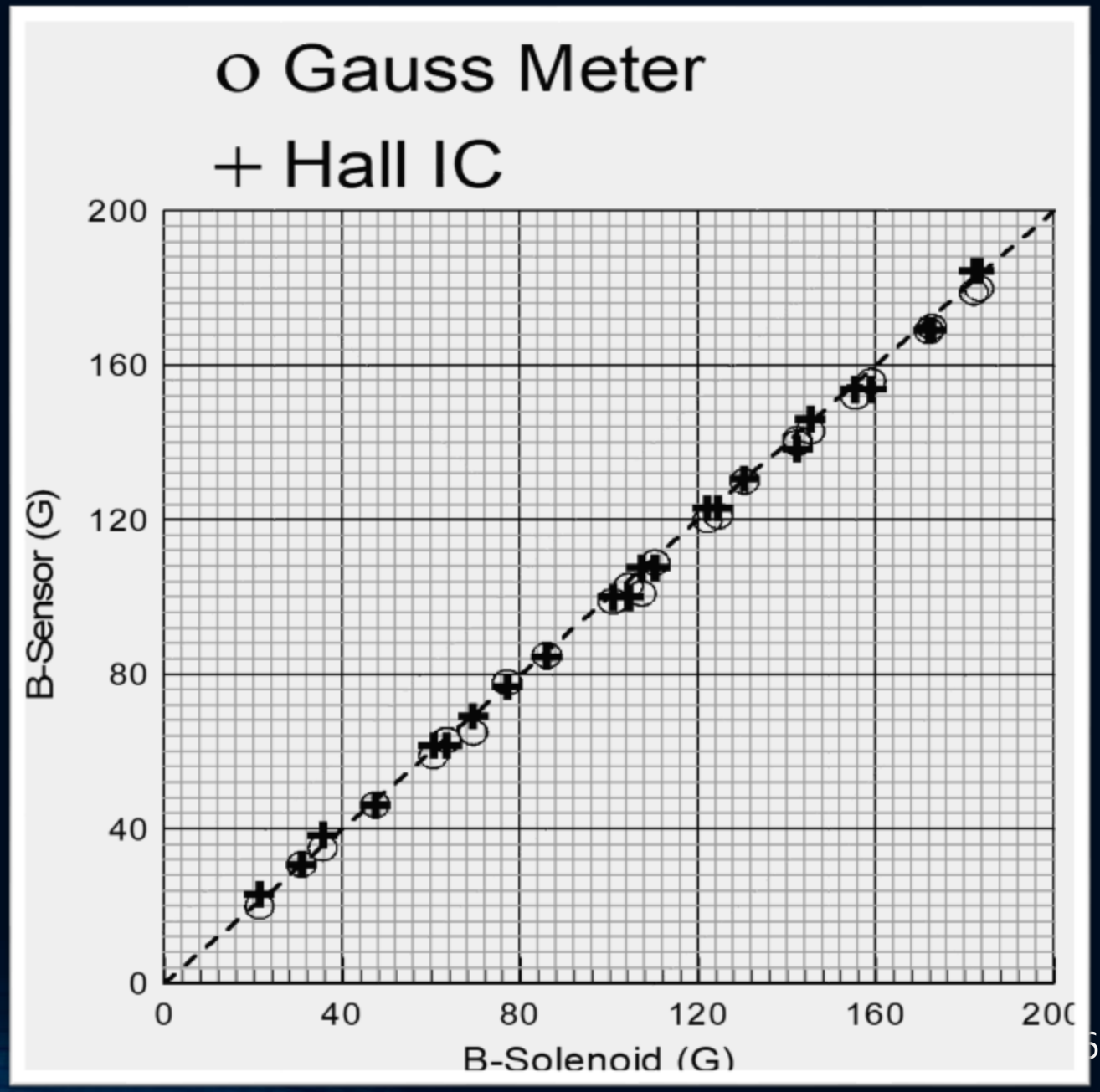


電壓源輸入

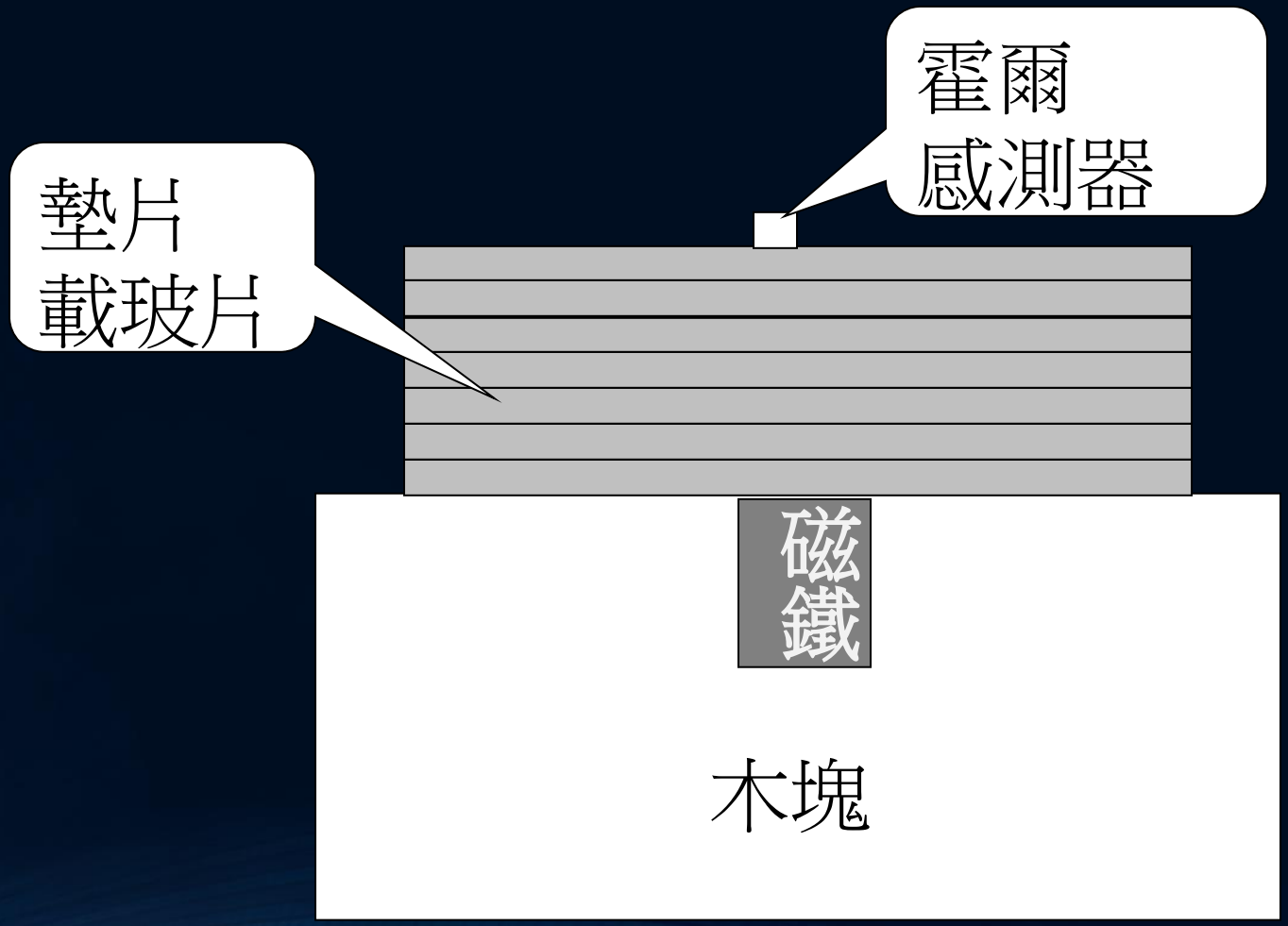
磁場電壓訊號輸出

霍爾感測模組
測試: 磁場校準

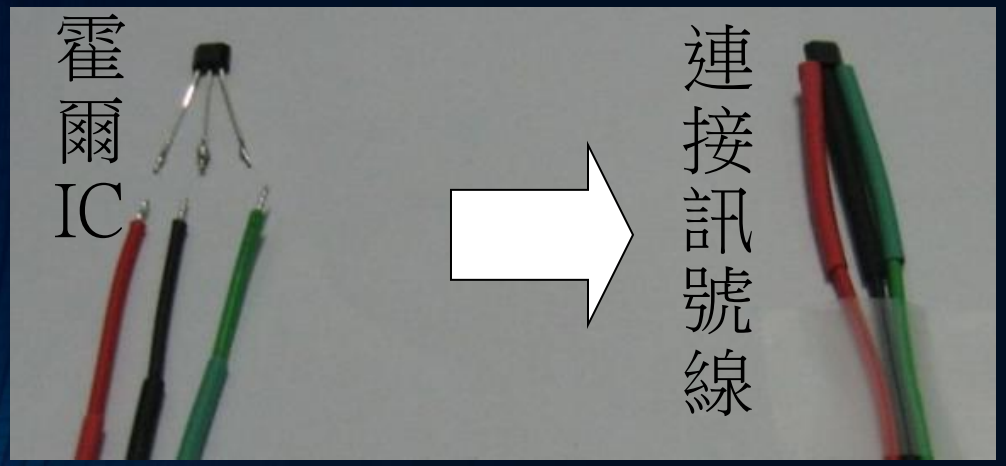
與Gauss Meter 相較

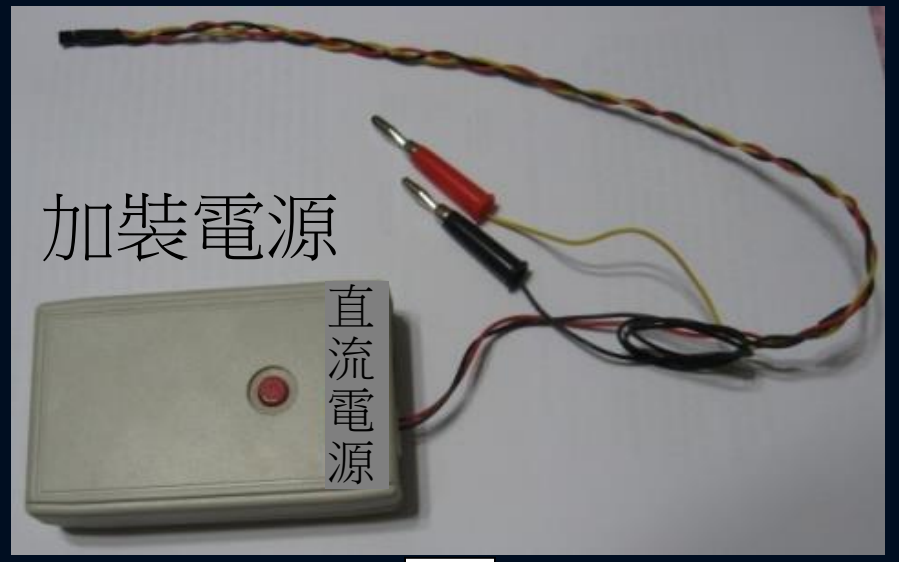


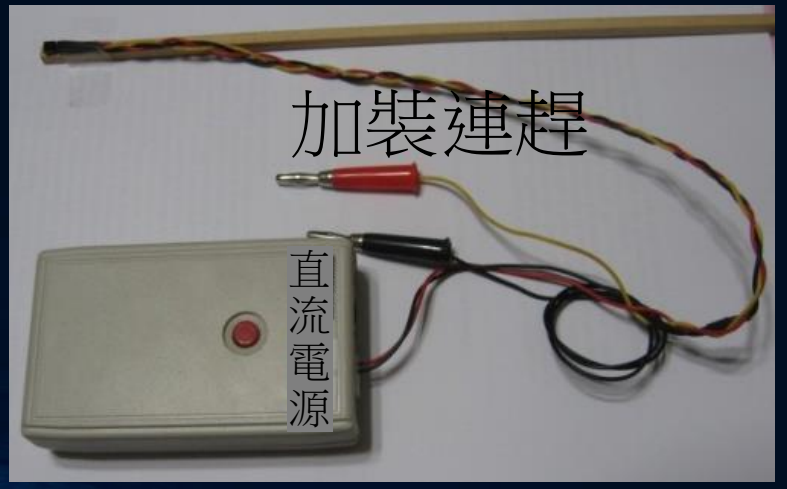
偶極磁場探究陽春版



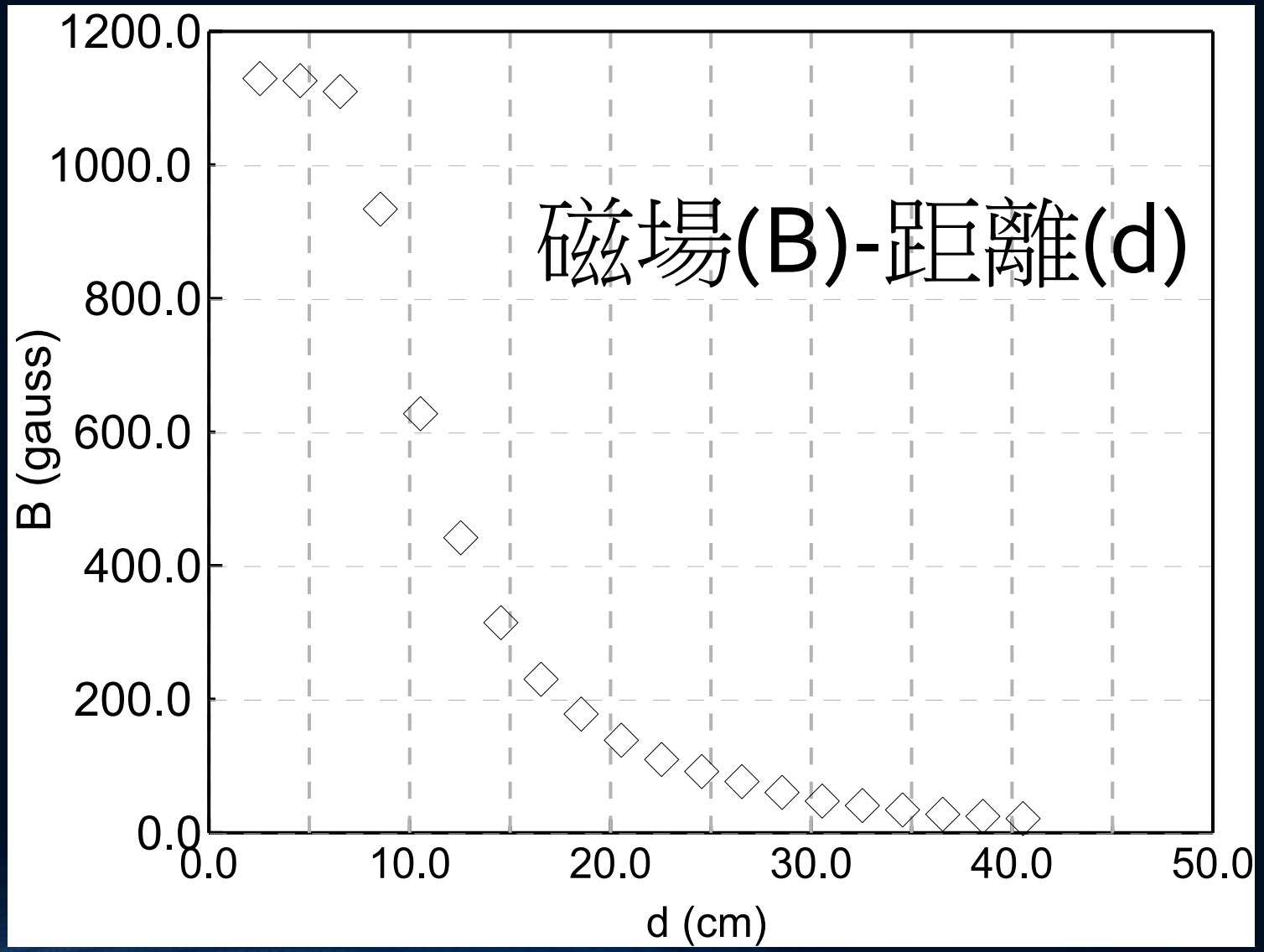
霍爾感測模組研發流程：



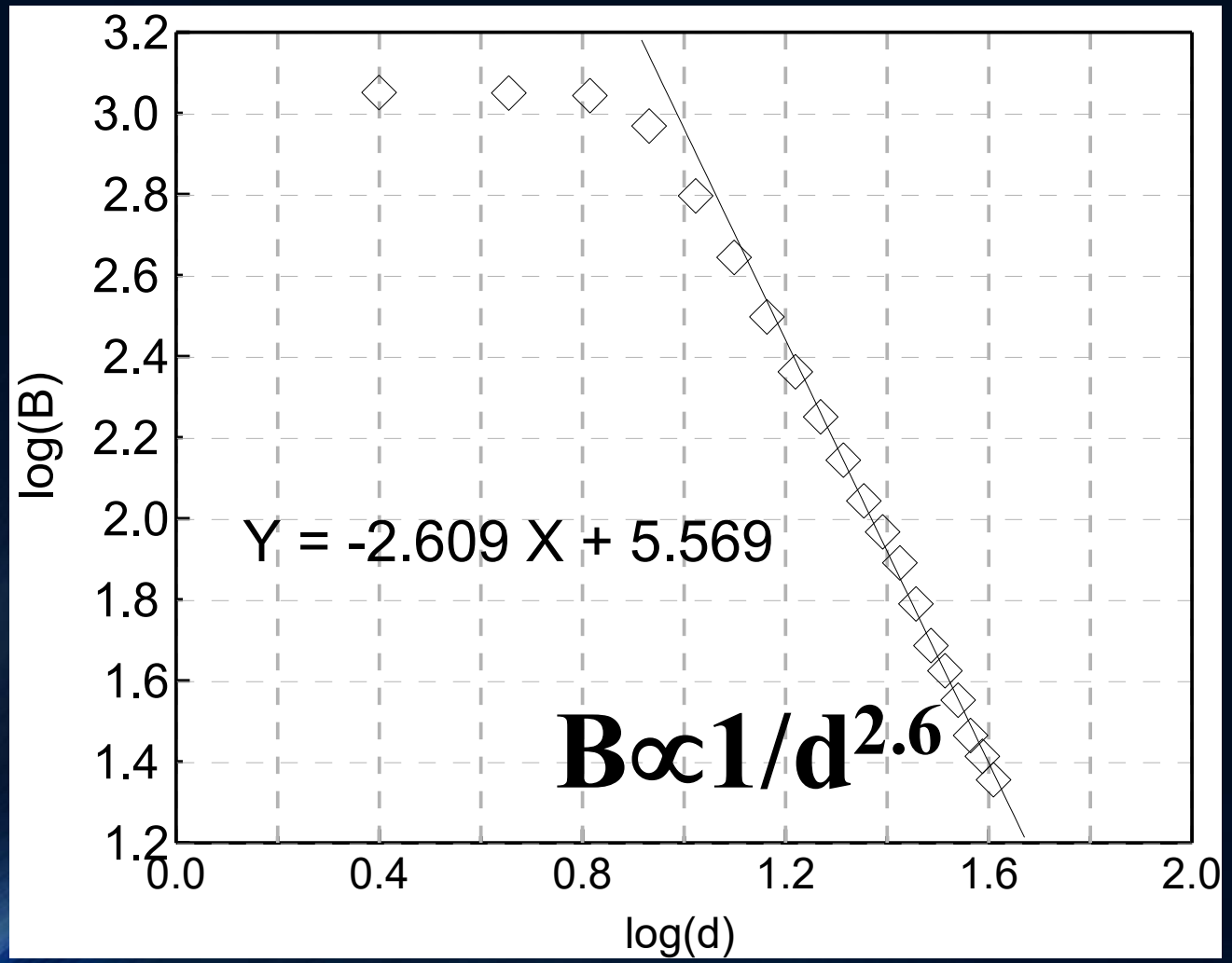




霍爾感測模組
探究數據：

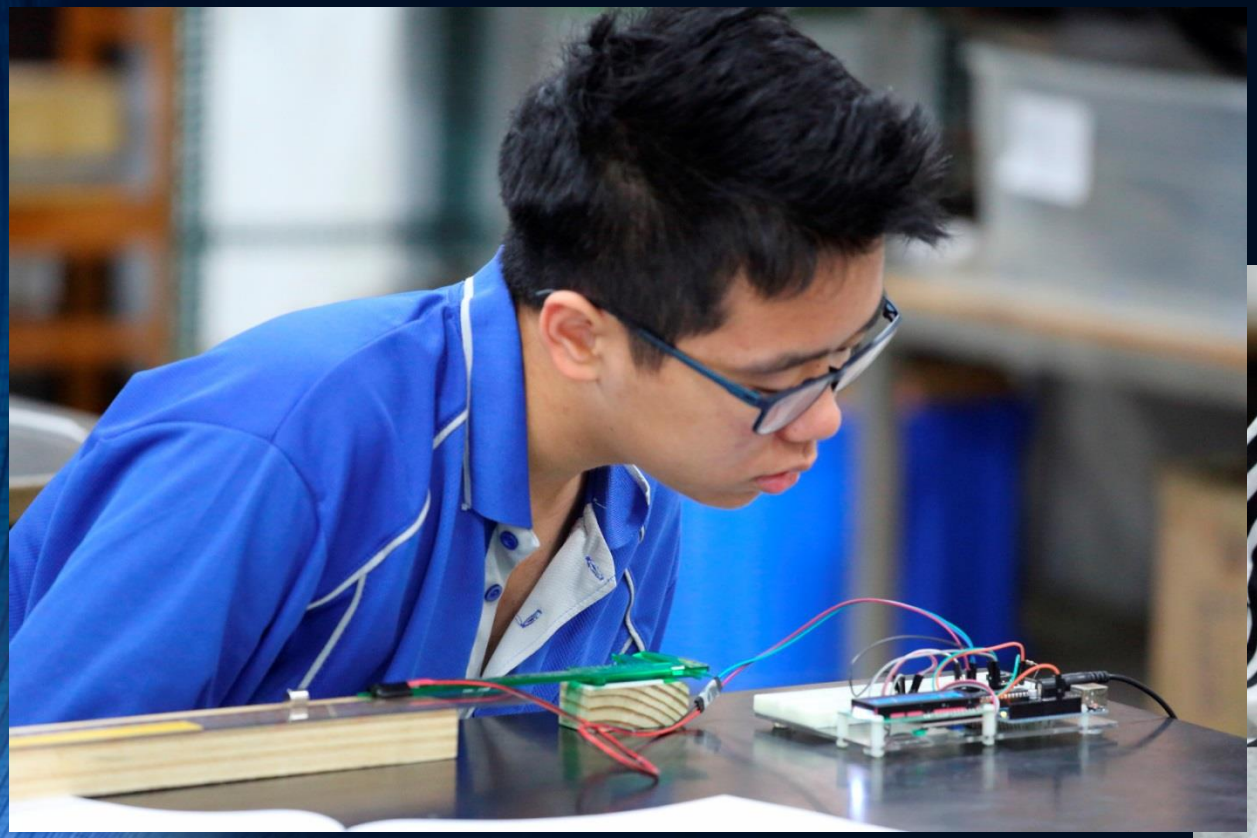

磁場(B)-距離(d)
B (gauss)
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
d (cm)

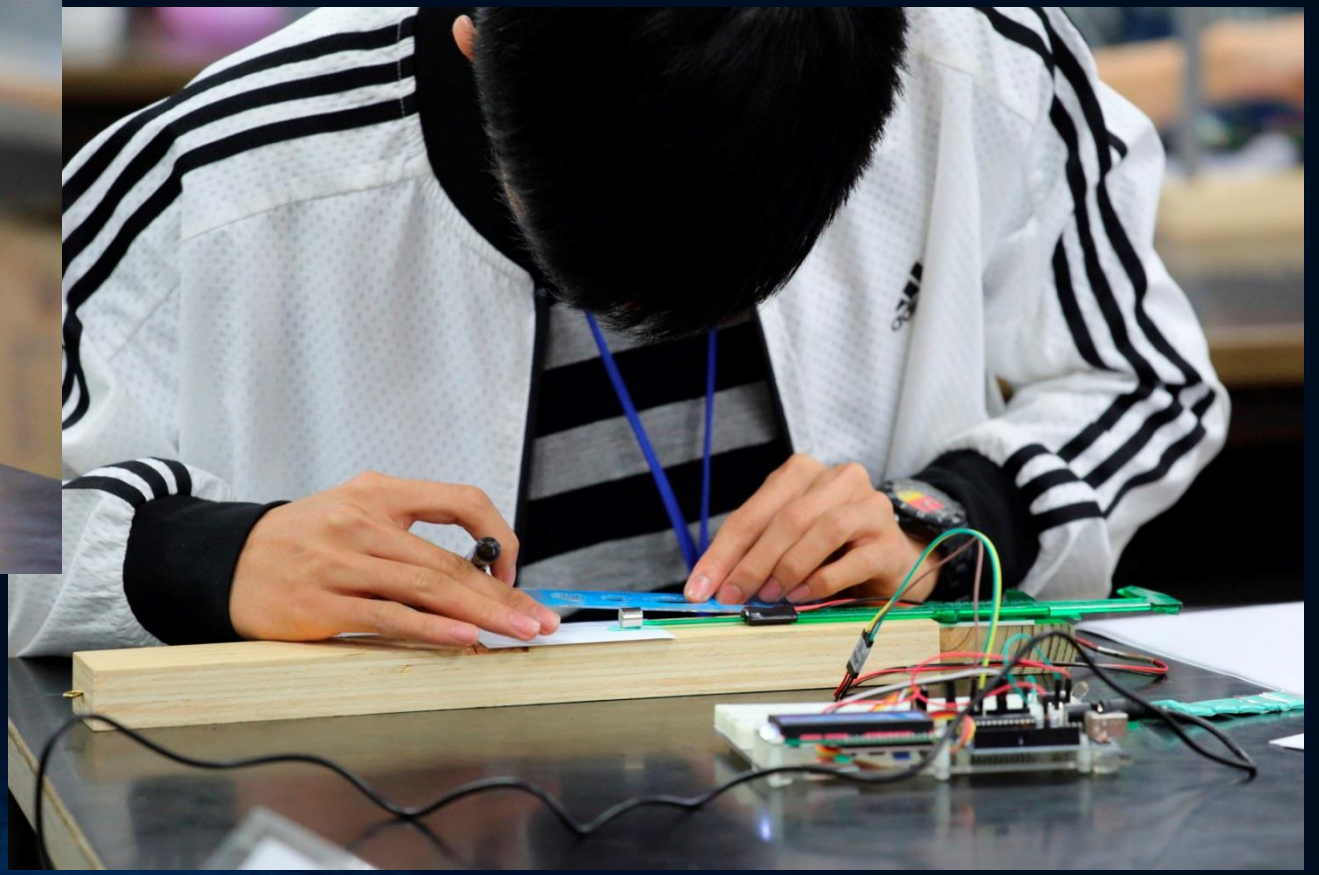
霍爾感測模組分析建模：



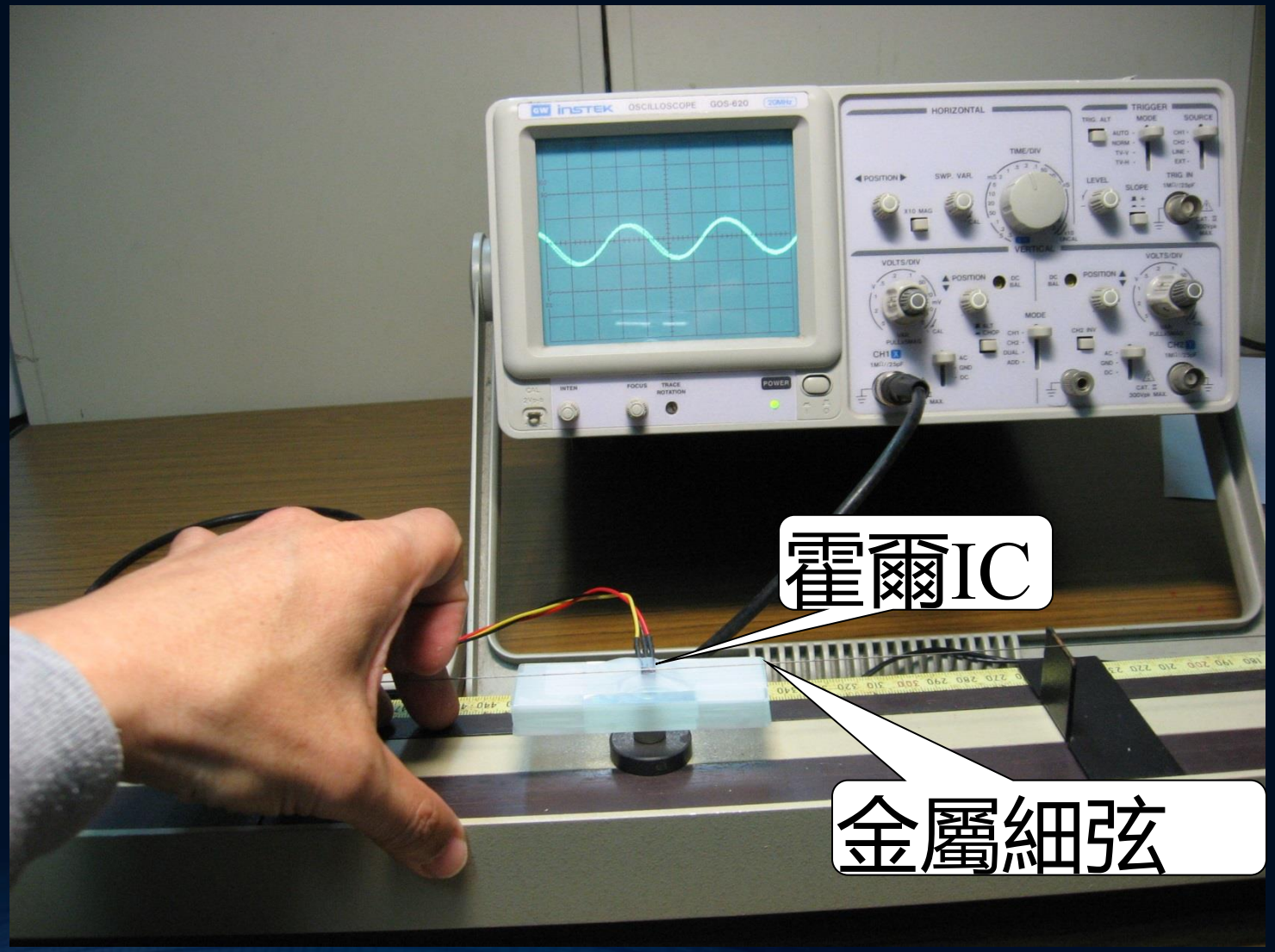
- 單極場 $\propto 1/r^2$
- 理想偶極場 $\propto 1/r^3$

霍爾感測模組
物理奧林匹亞探究測試

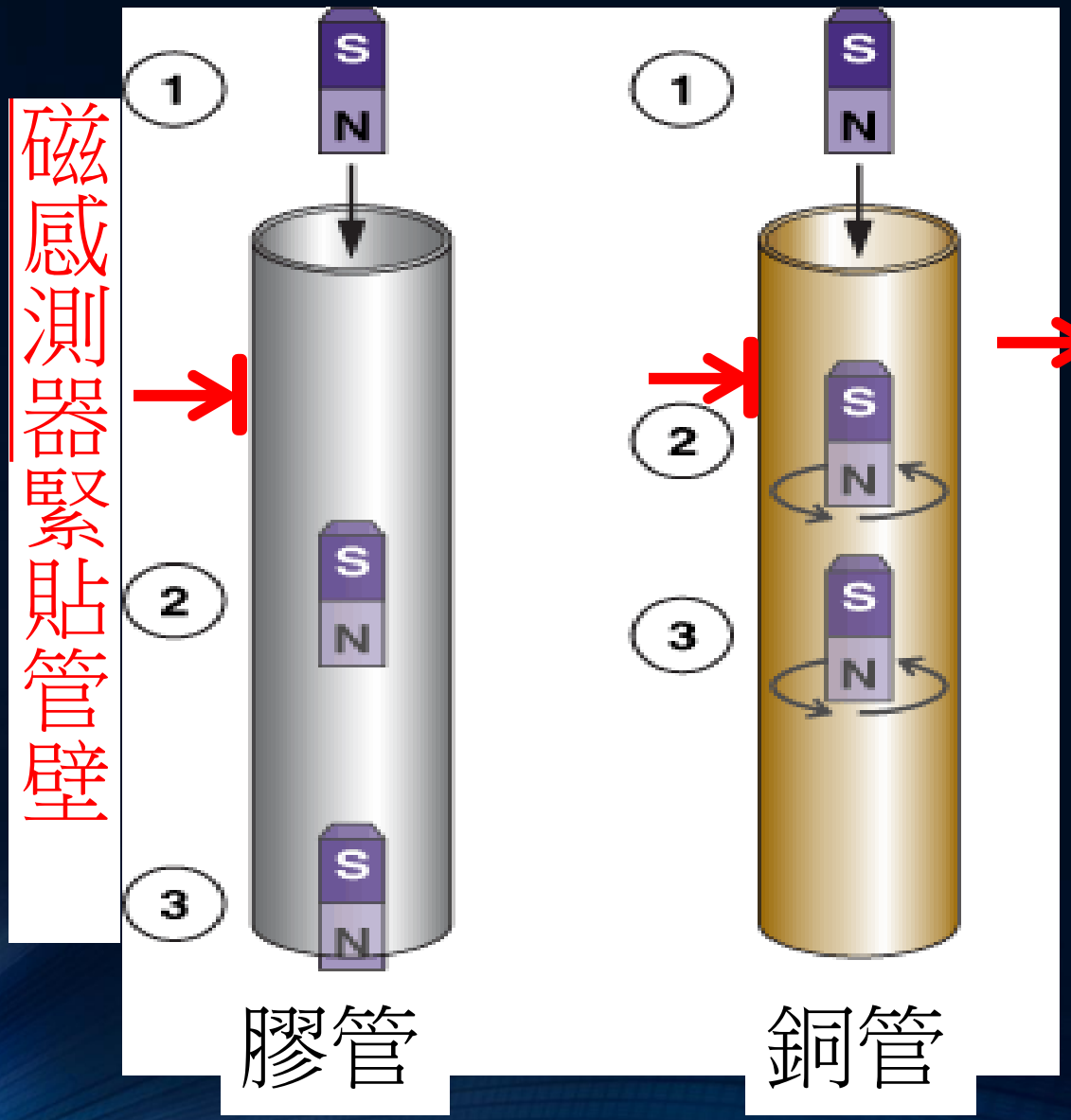




霍爾感測模組
弦波探究



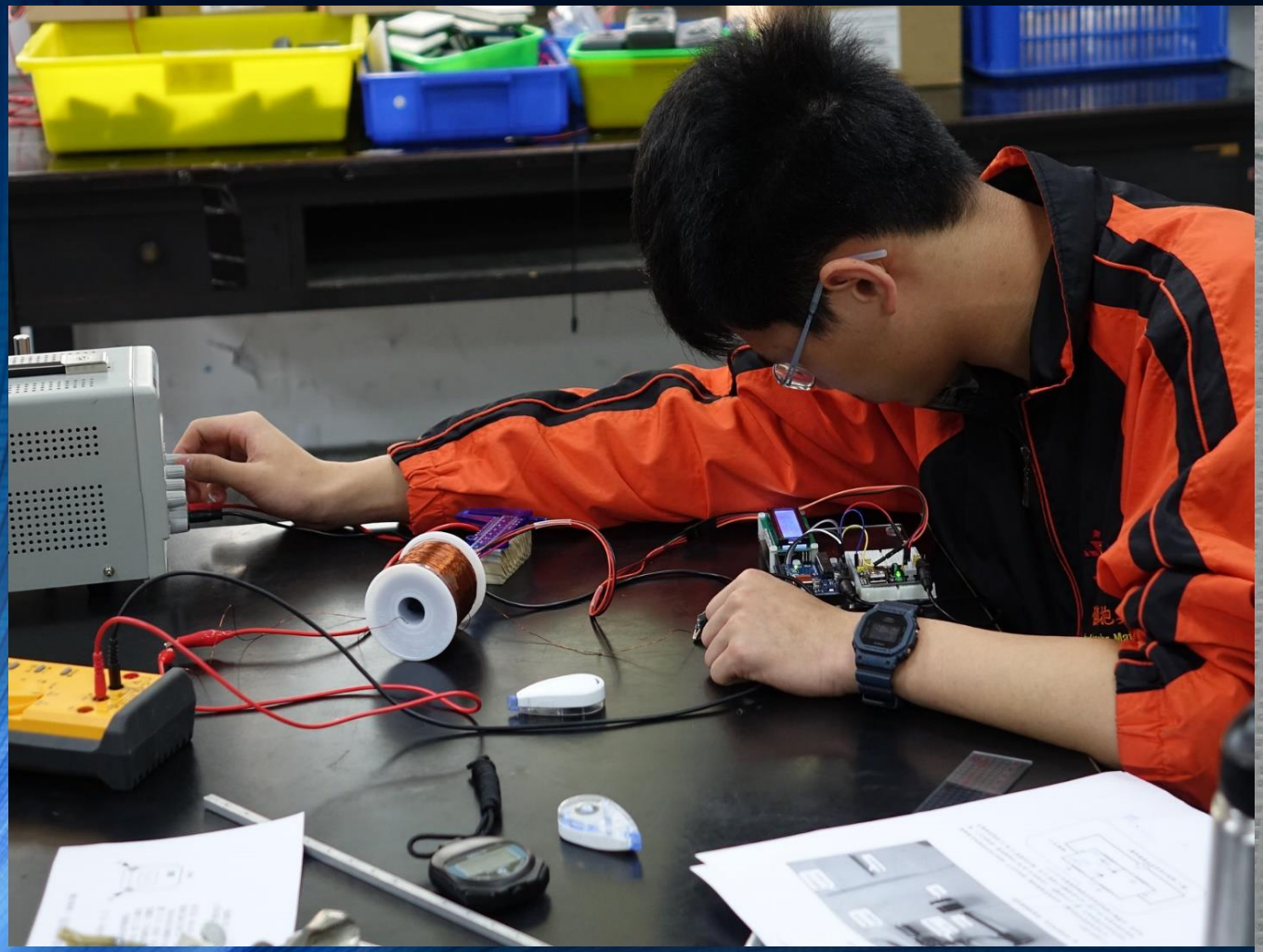
霍爾感測模組：磁剎車原理探究

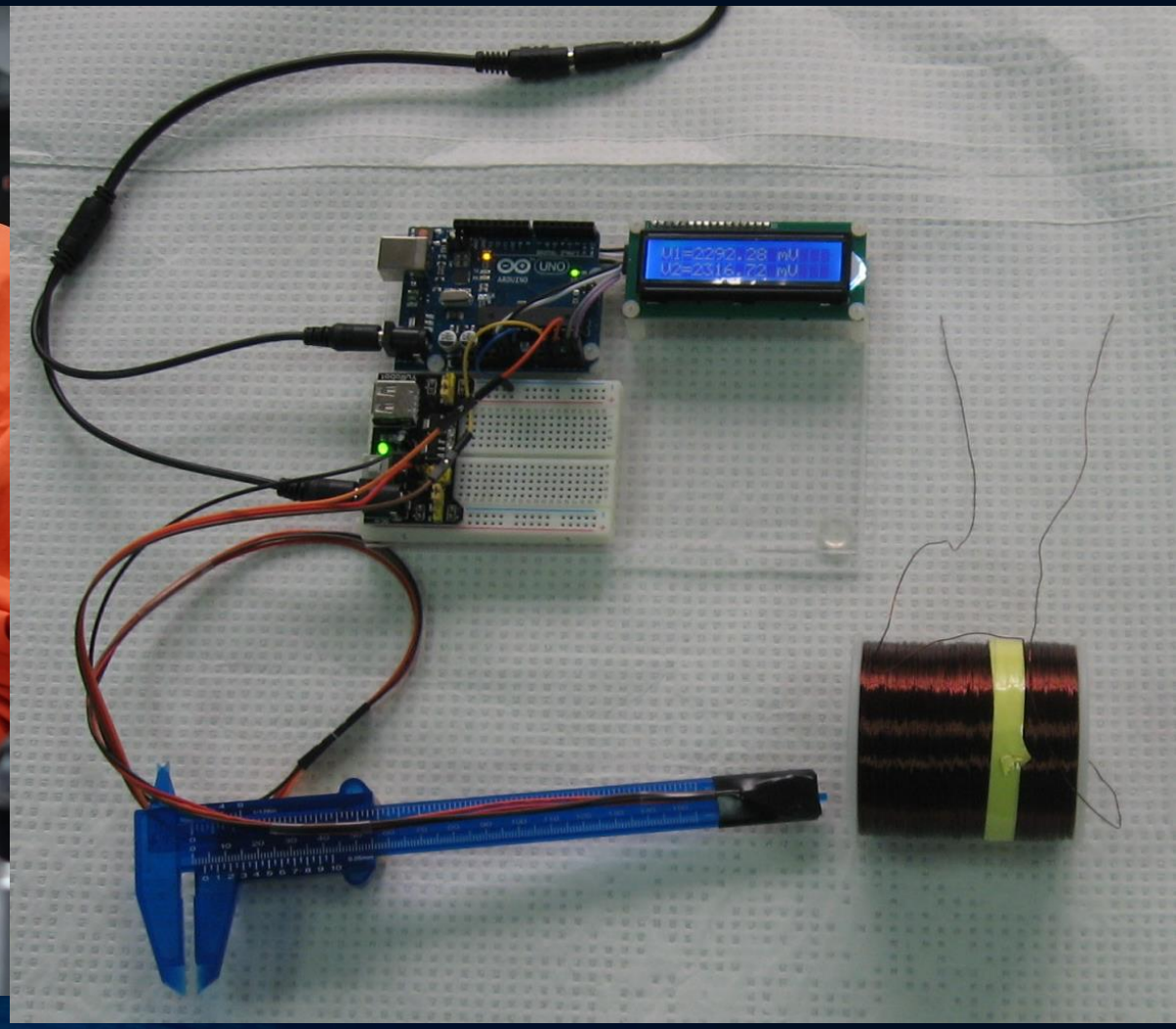


銅管：感應電流、磁剎車

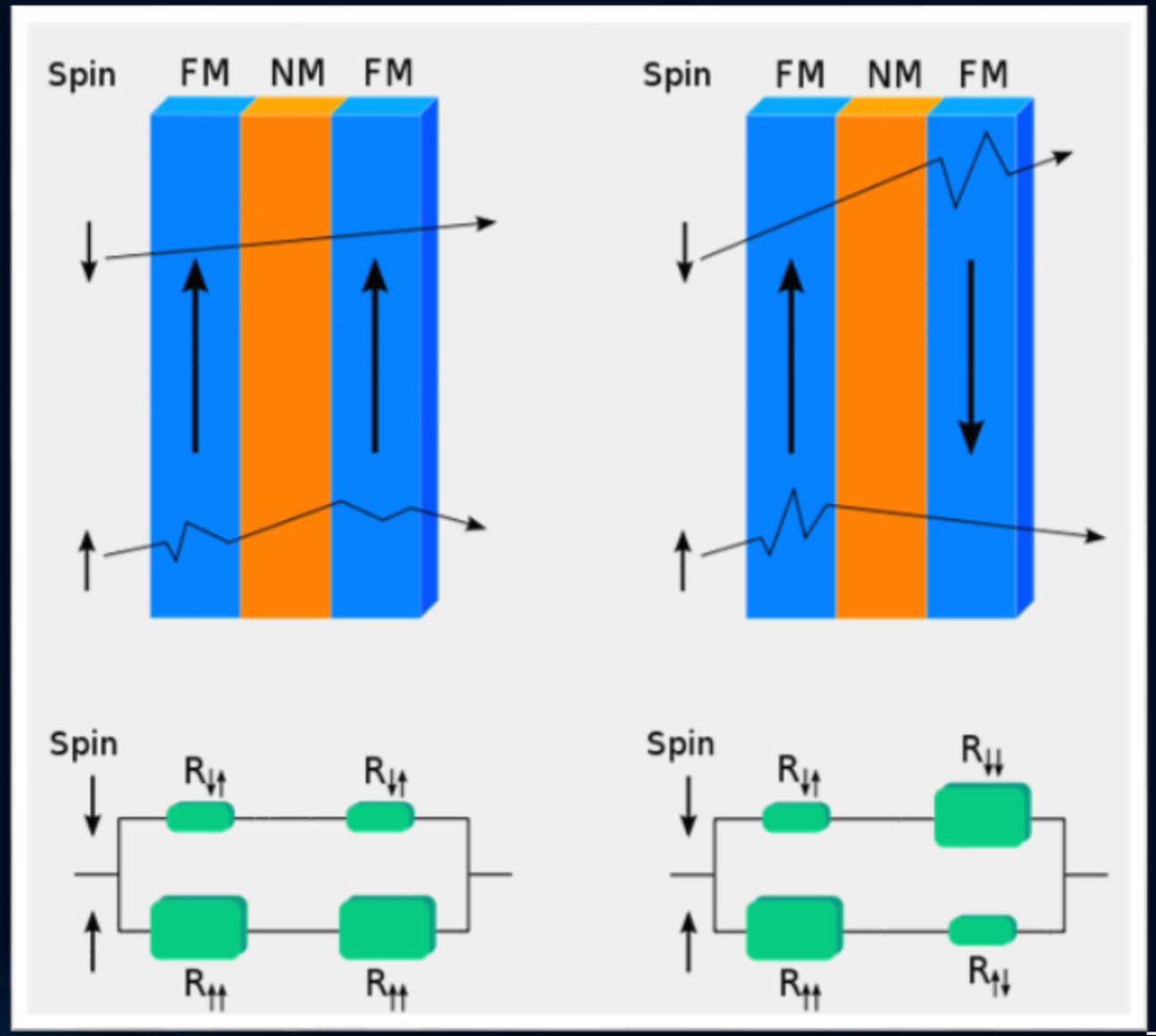

同樂!

線圈磁場探究: 巨磁阻感測器

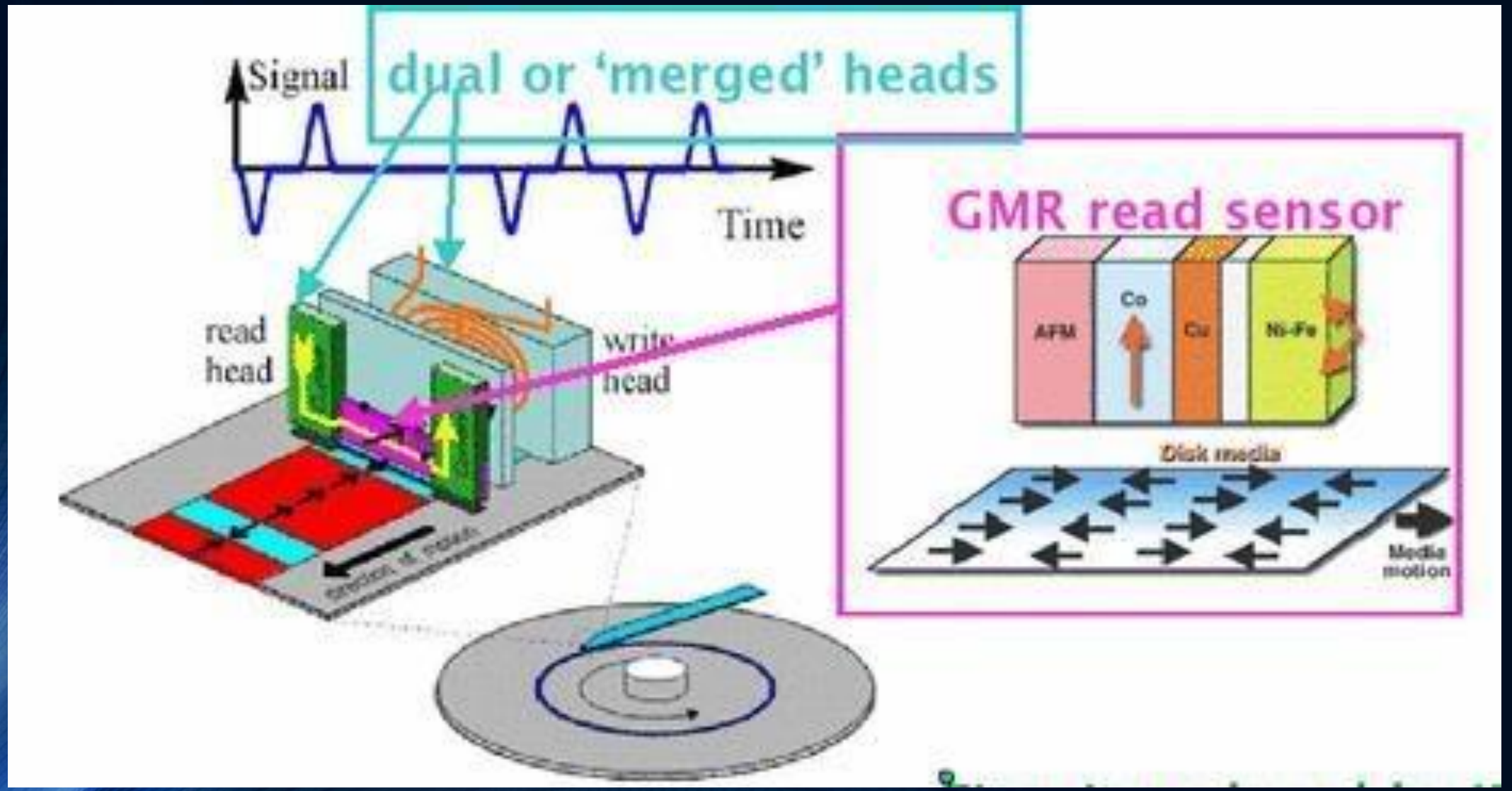




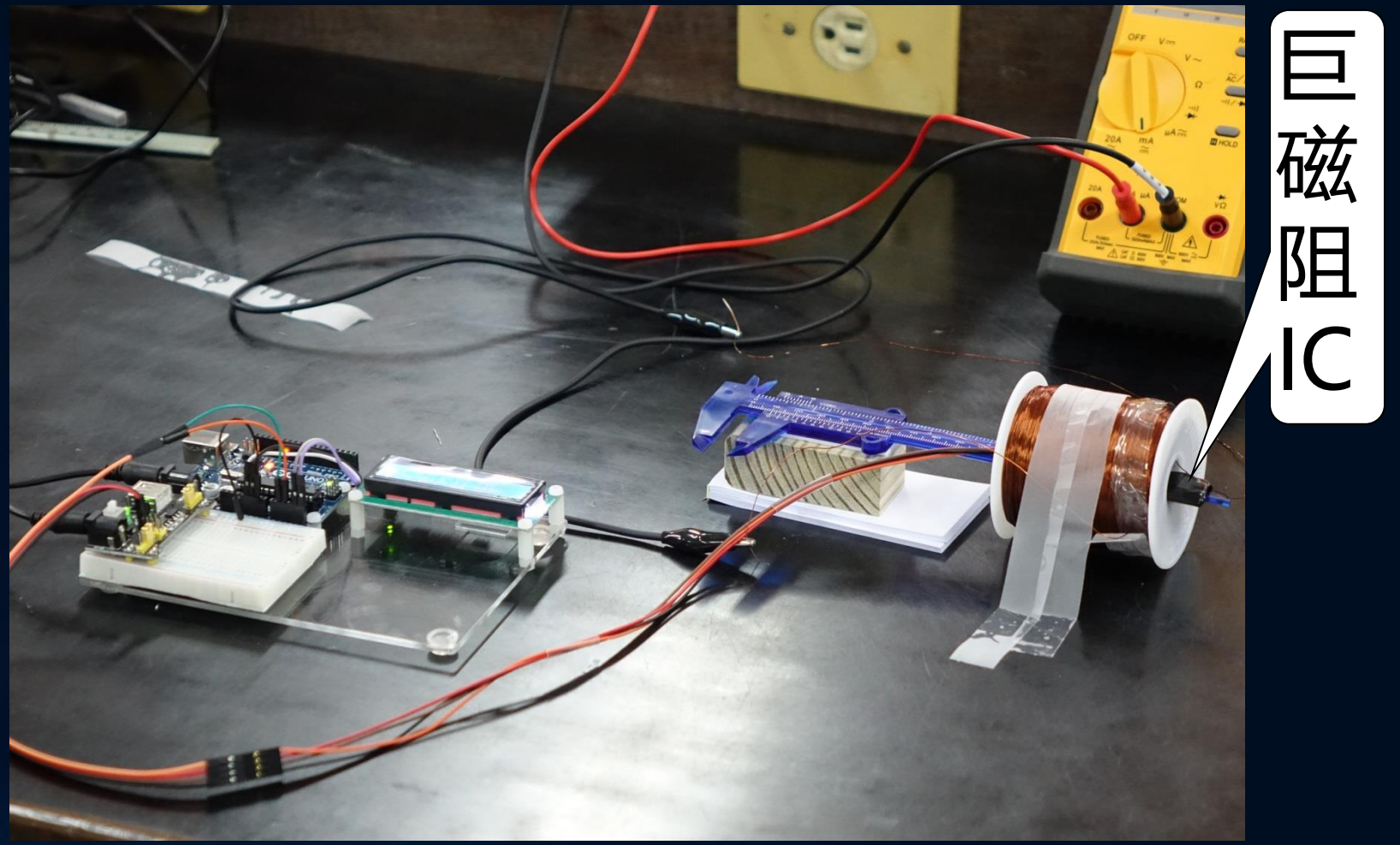
巨磁阻效應(GMR: 1988 Nobel prize)



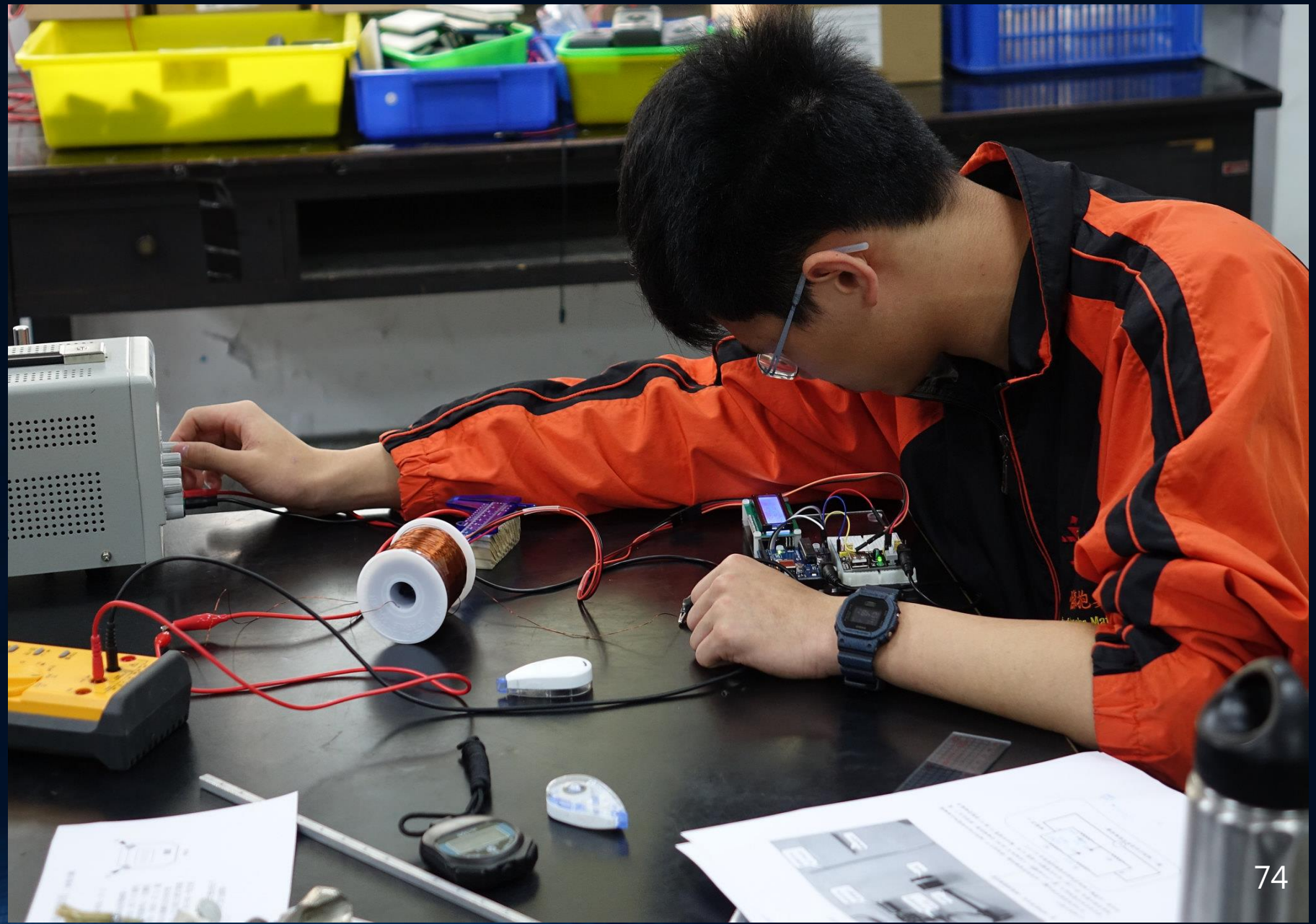
巨磁阻感測模組
產業應用：硬碟讀頭



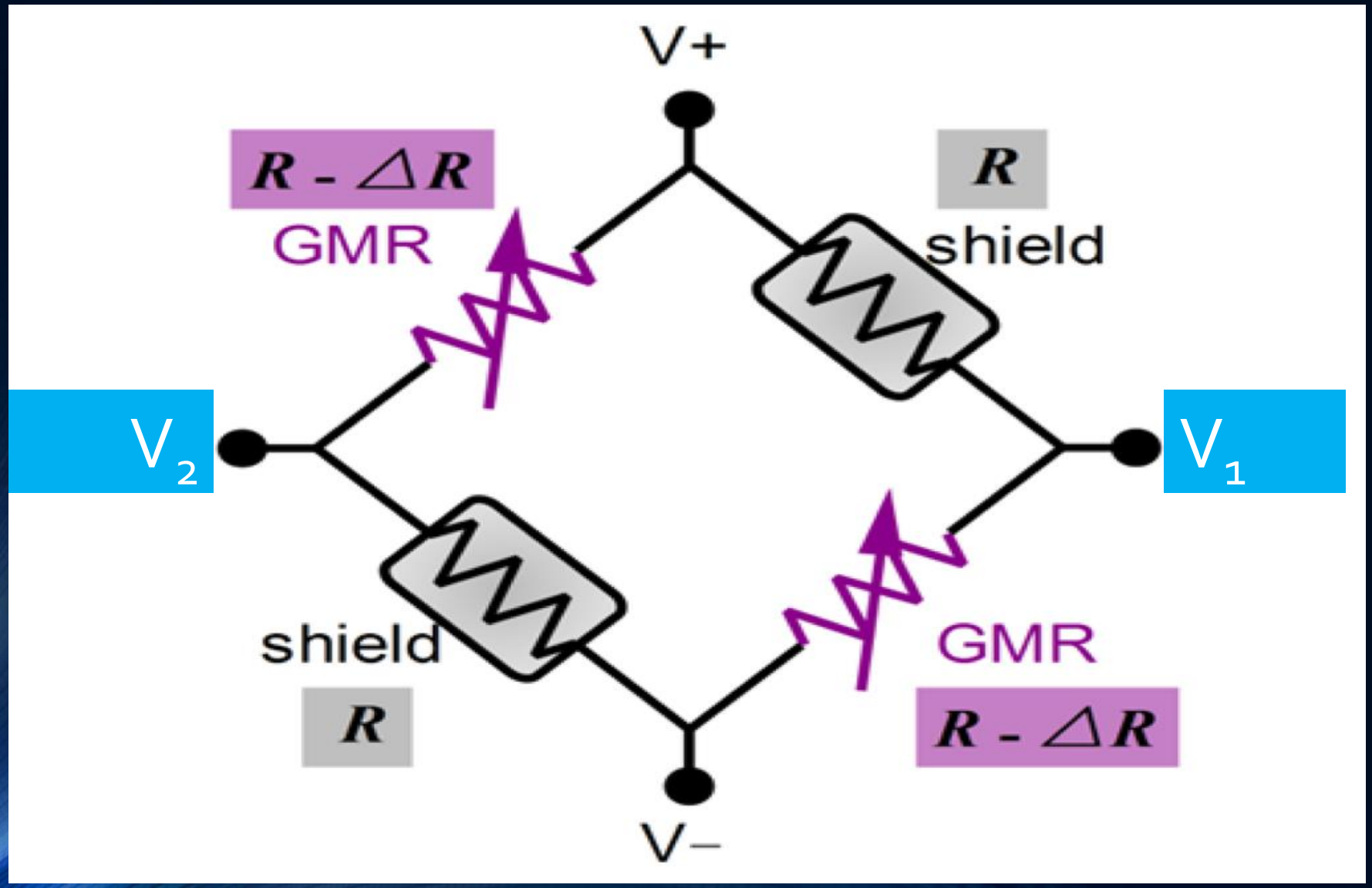
巨磁阻感測模組
線圈磁場探究



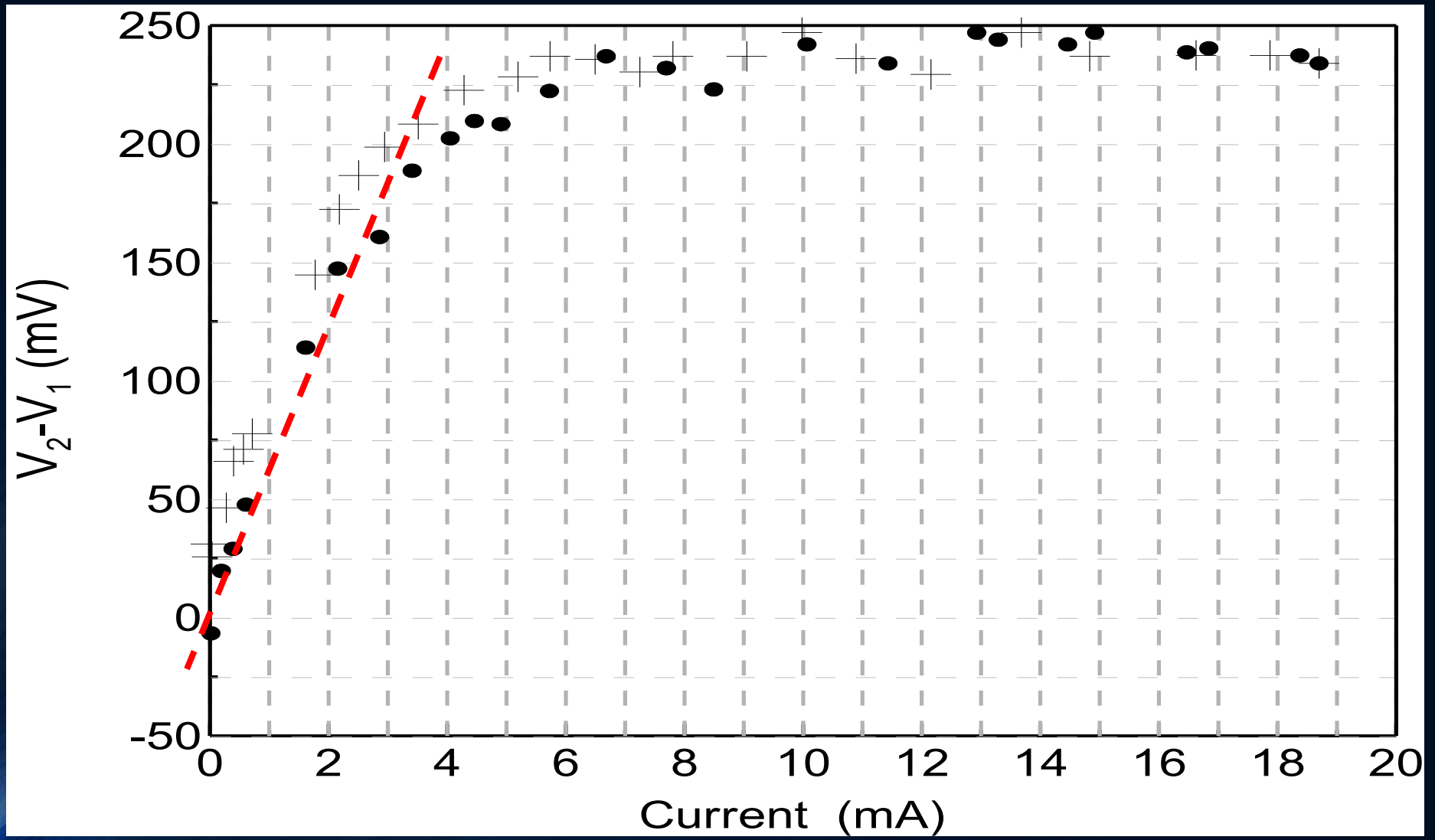
巨磁阻探究模組: 物理奧林匹亞探究測試



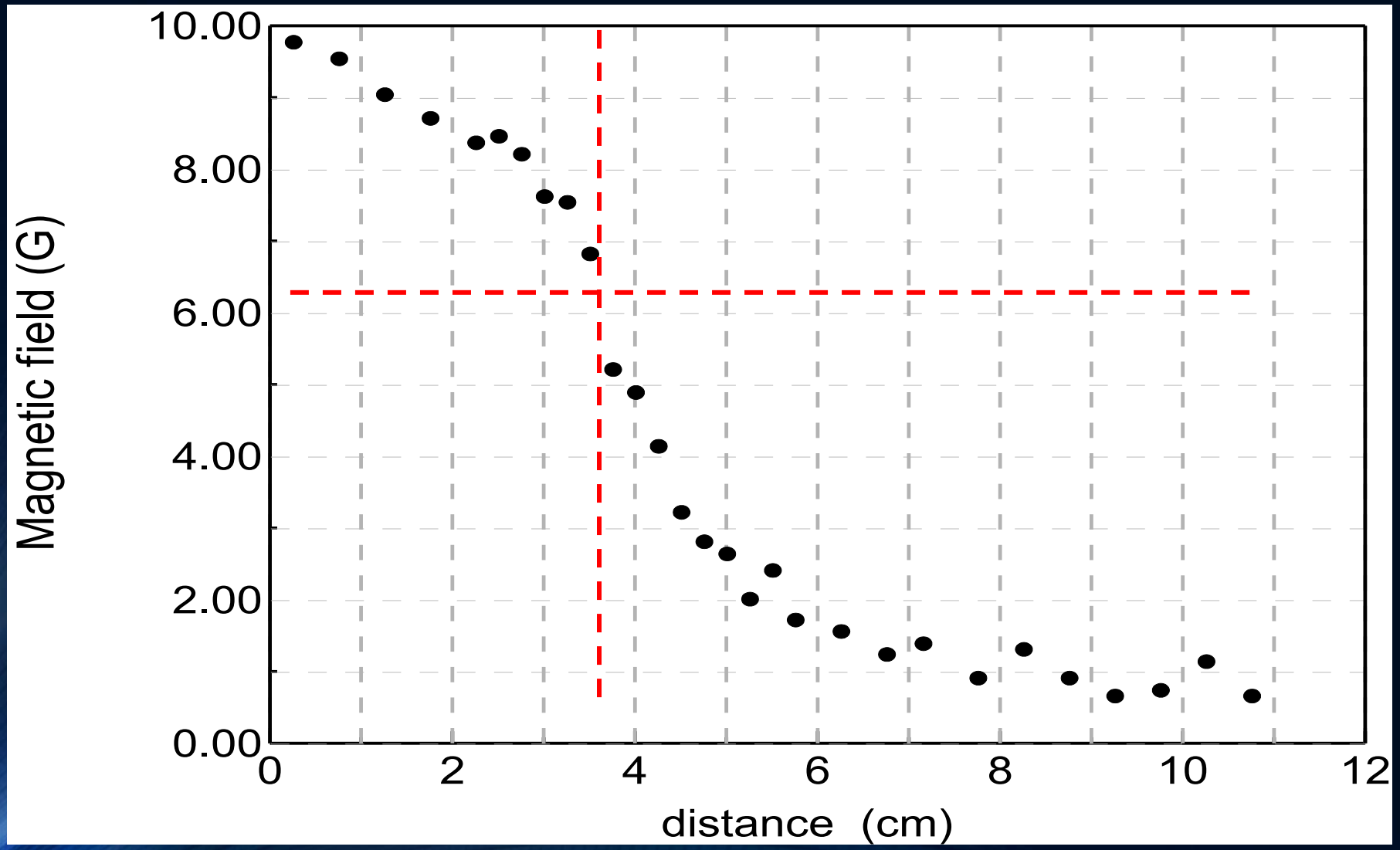
巨磁阻感測器:
電橋轉換電阻為電壓(V_2-V_1)



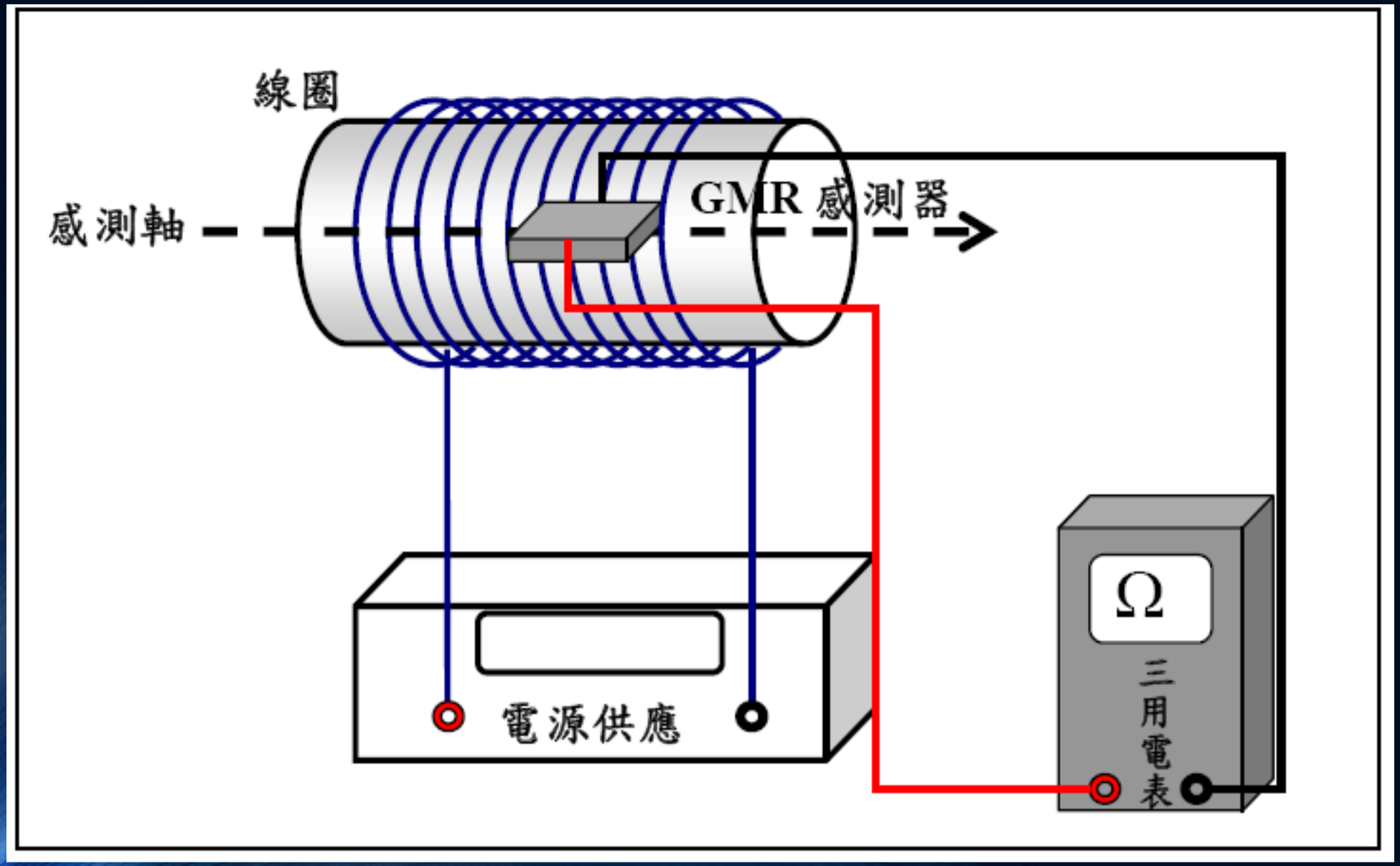
校正磁場數據



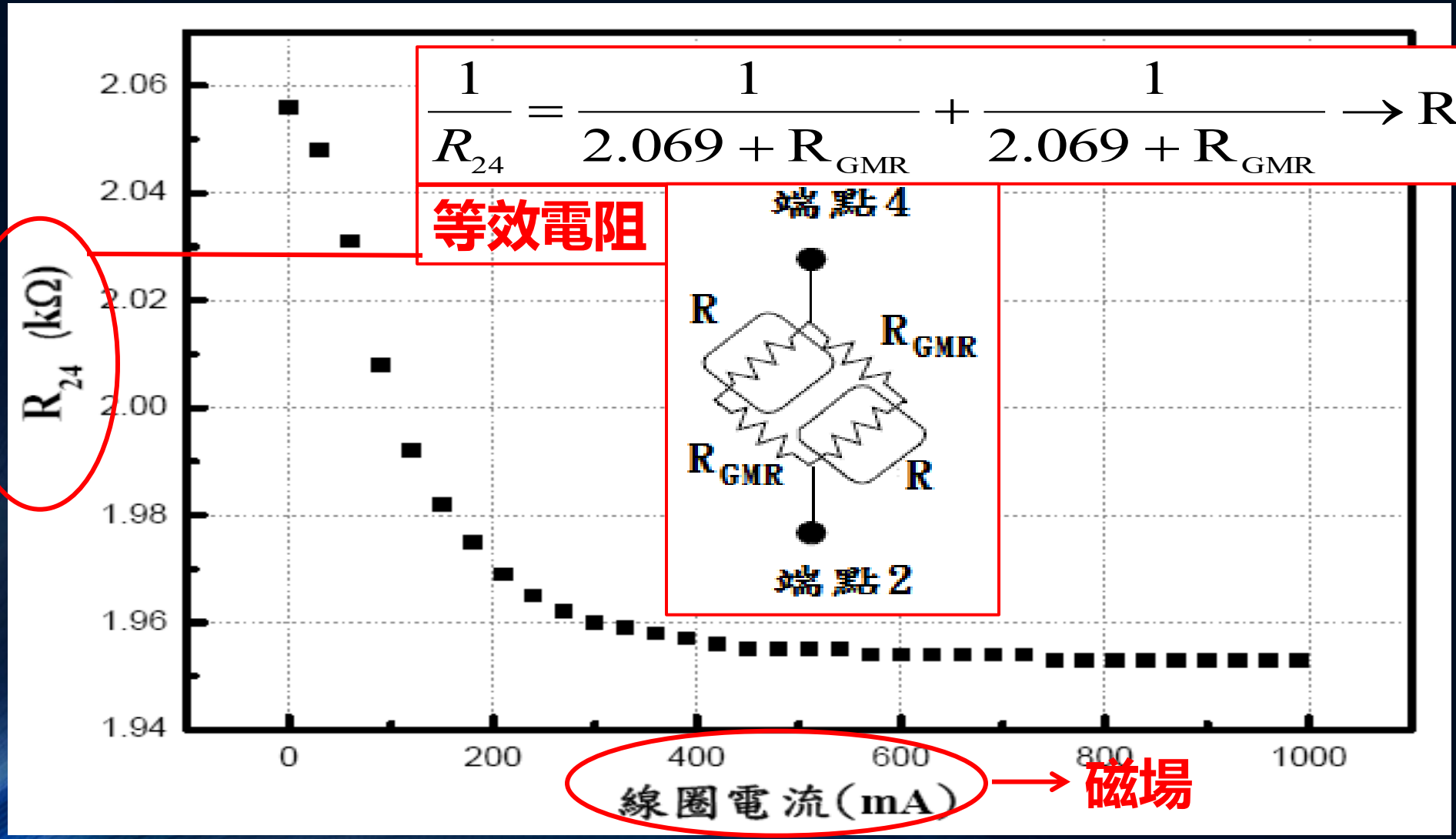
巨磁阻探究模組: 線圈磁場分布



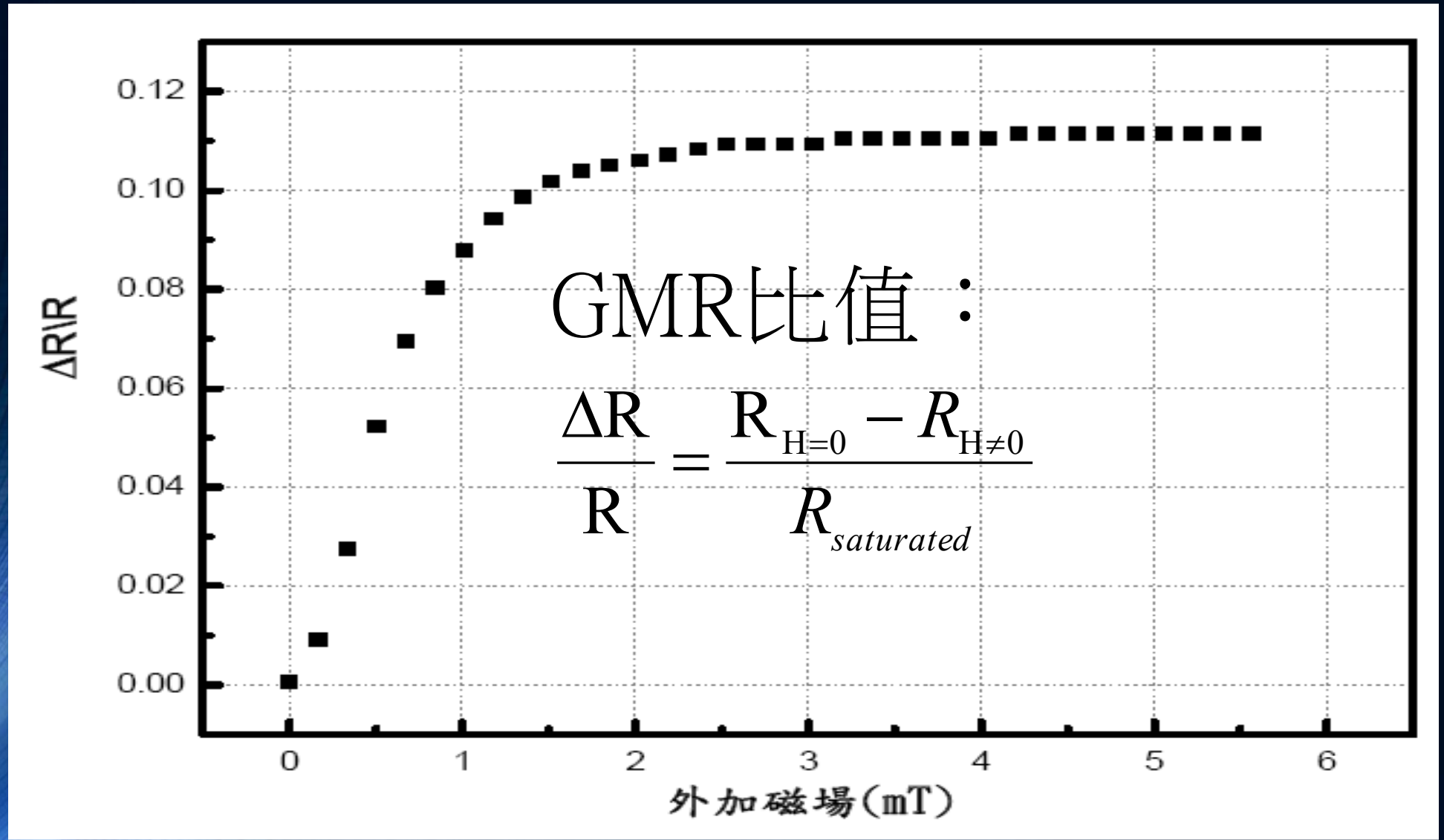
巨磁阻(GMR)效應探究



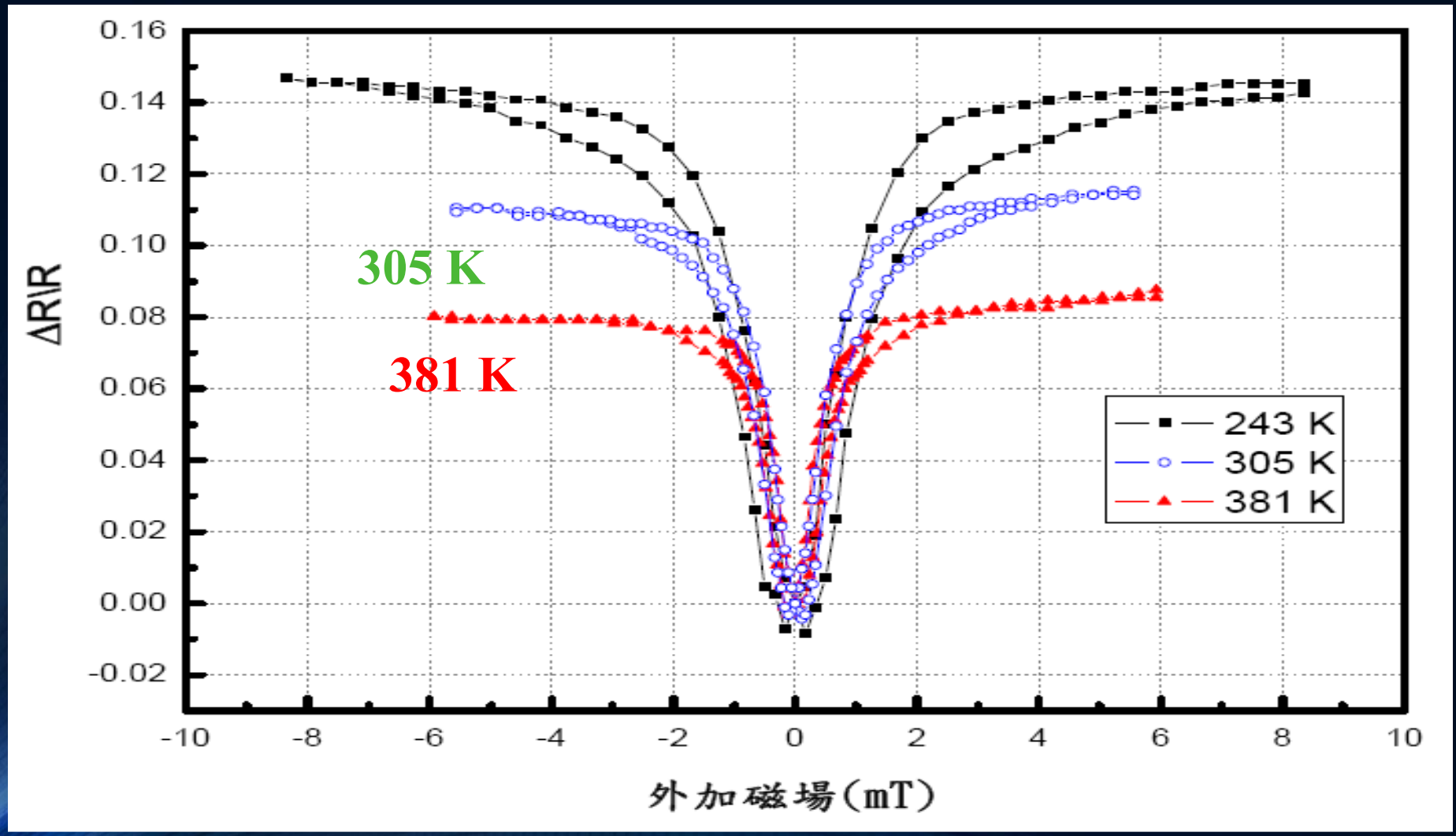
巨磁阻效應探究：實驗數據



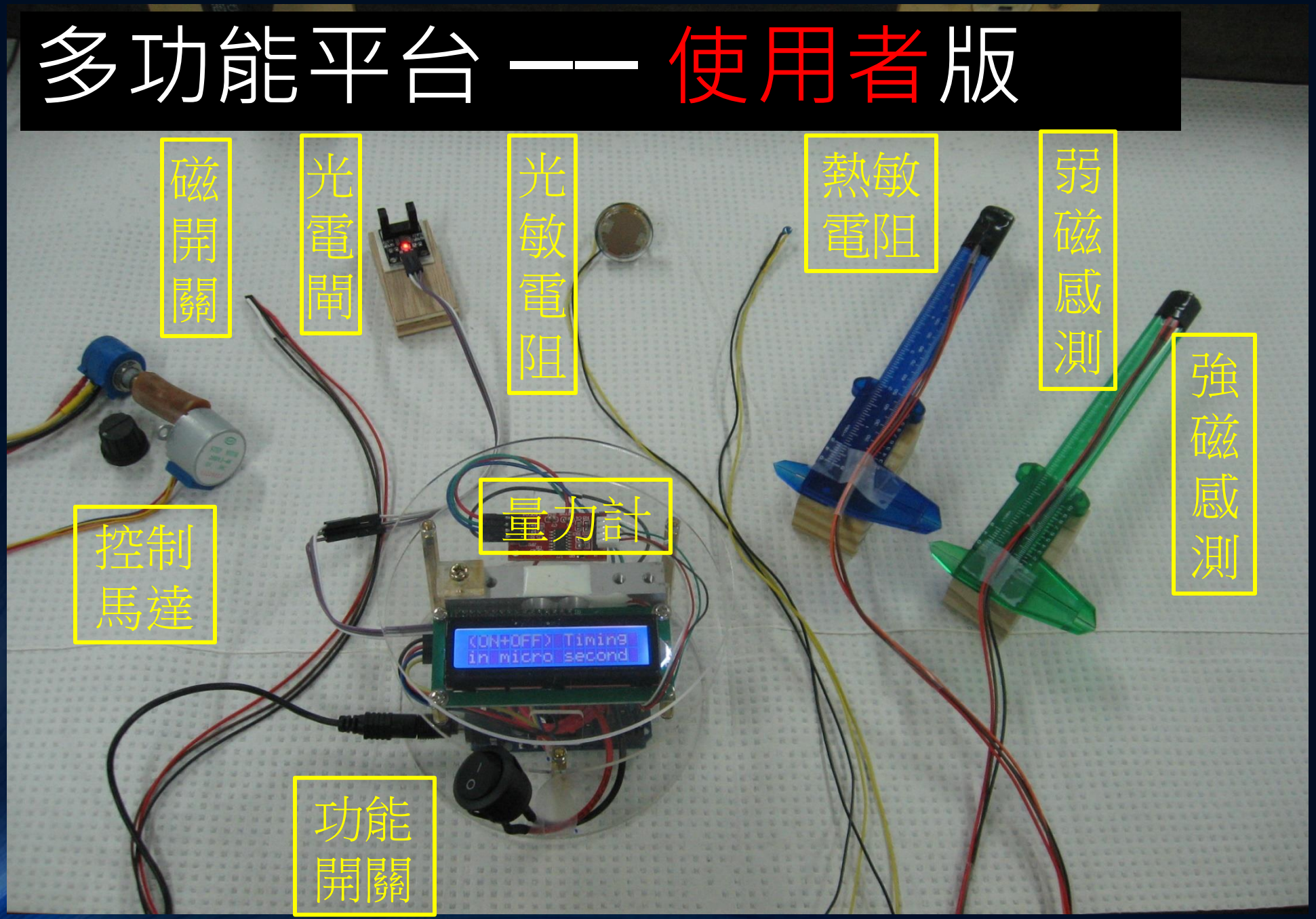
巨磁阻(GMR)效應探究：數據轉換



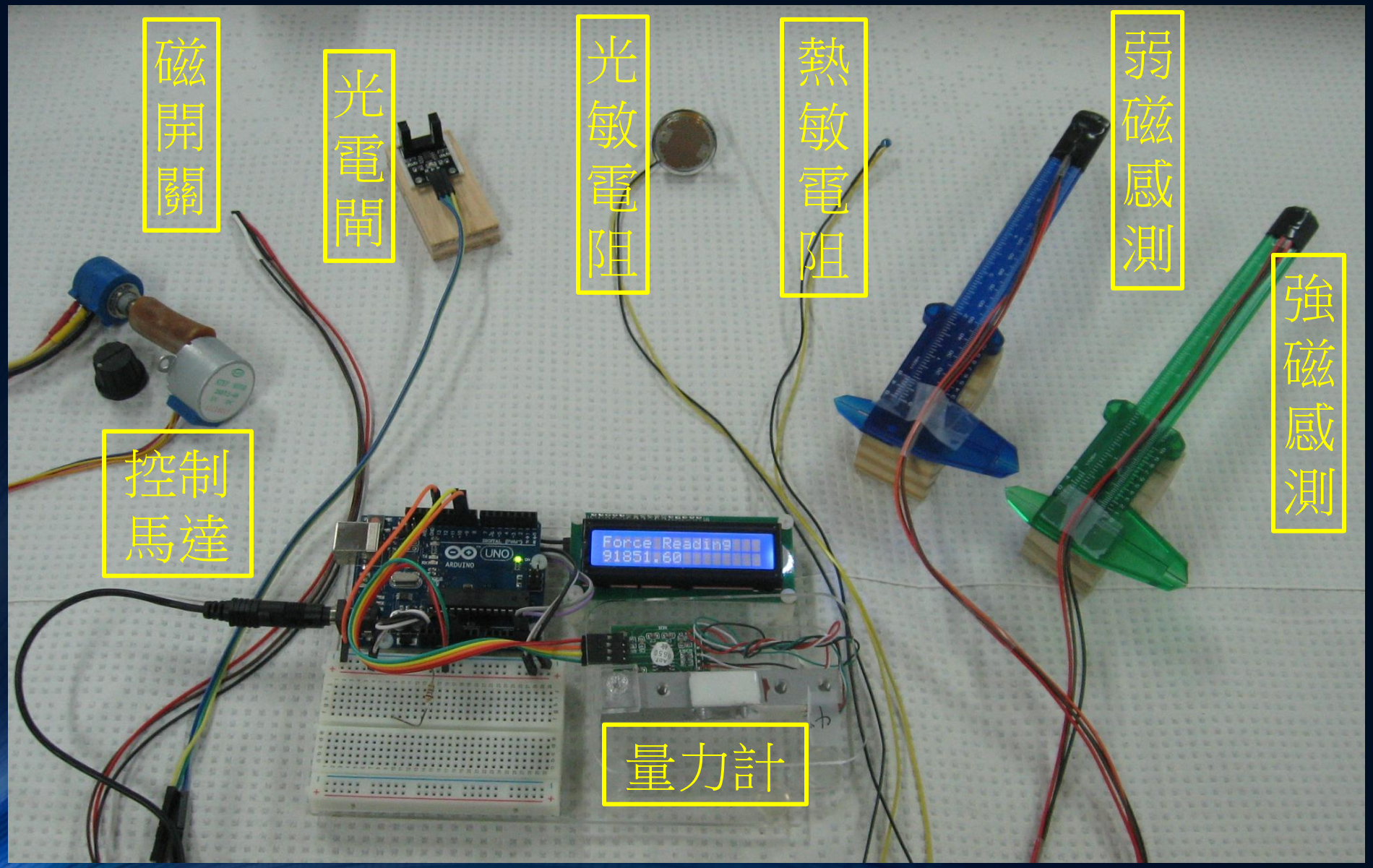
巨磁阻(GMR)效應探究：溫度效應



多功能平台 —— 使用者版


磁開關
光電閘
光敏電阻
熱敏電阻
弱磁感測
強磁感測
控制馬達
量力計
功能開關
(ON+OFF) Timing
in micro second

多功平台——開發者版



光學:

減輕負荷: 將3維現象，減輕為2維實作

1.幾何光學:

以2維圓柱，模擬3維水珠大圓之彩虹原理

2.物理光學:

以2維繞射，模擬3維XD(X-ray Diffraction)

光學 以維圓柱 模擬 維水珠之 彩虹原理

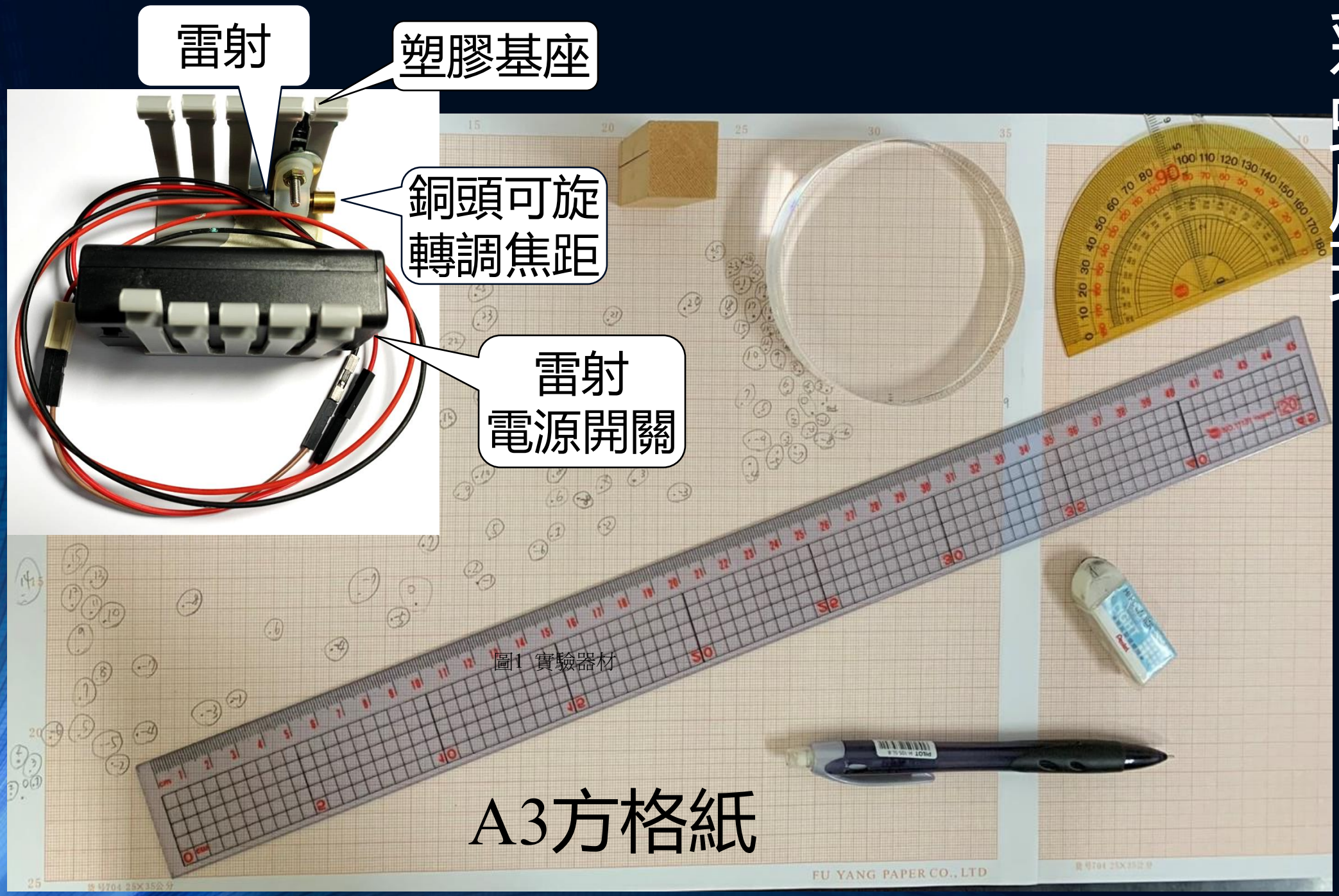
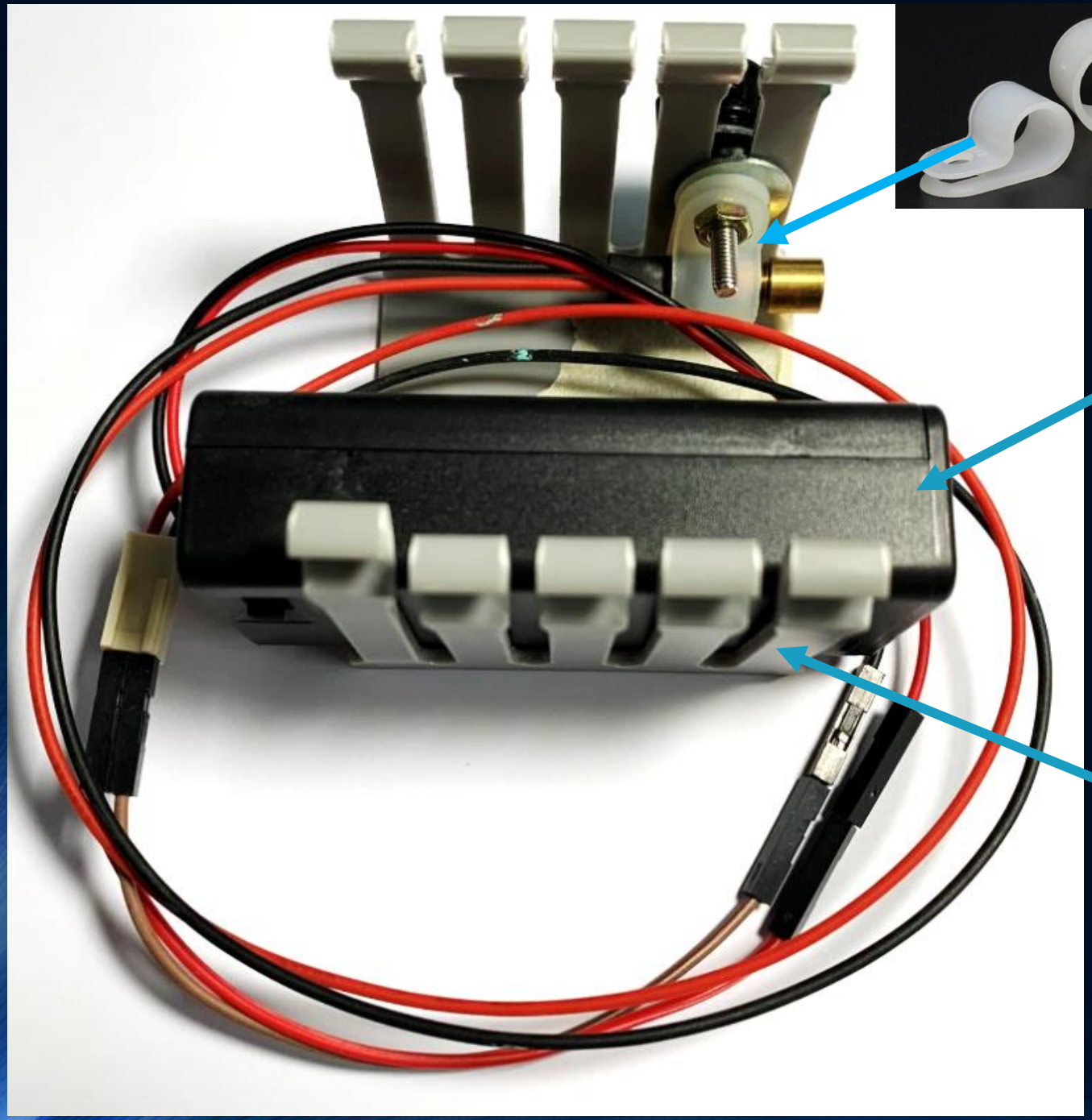
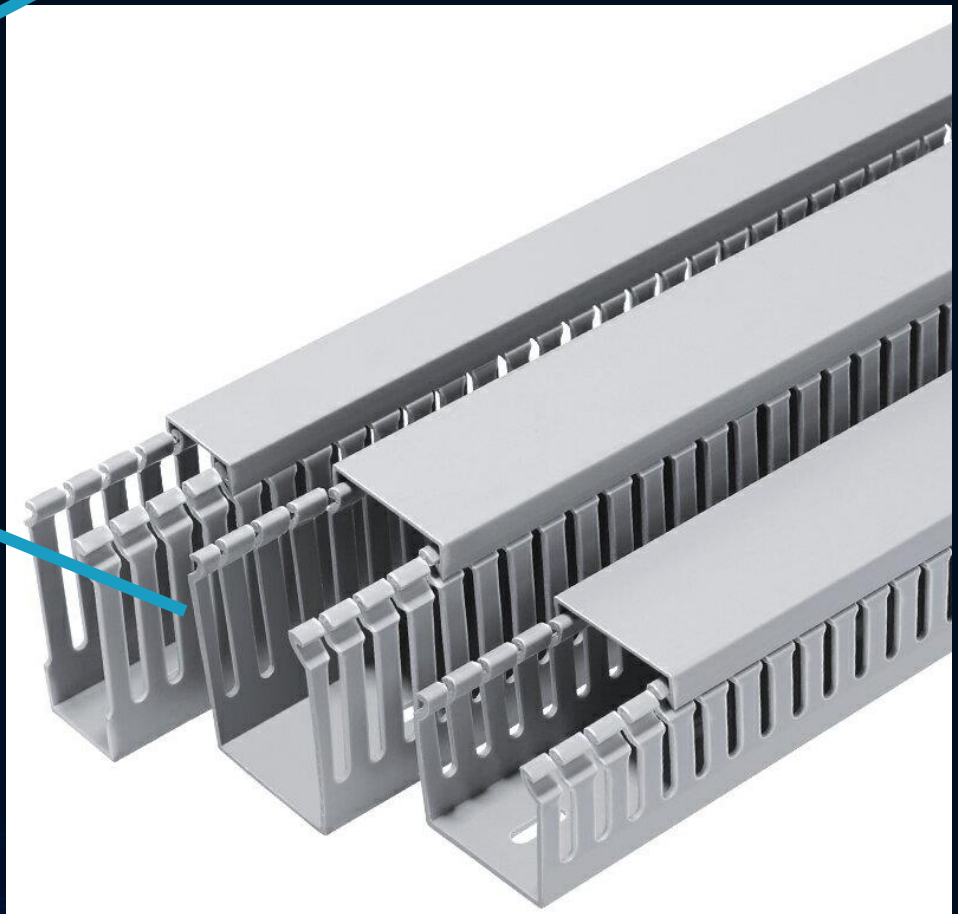


圖1 實驗器材

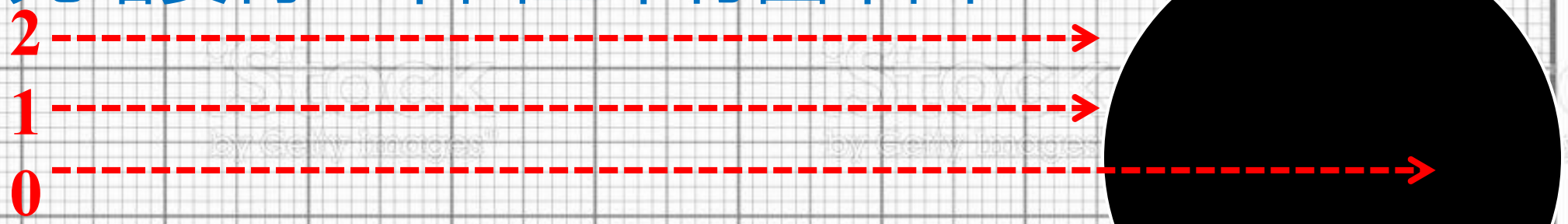
產業零件：



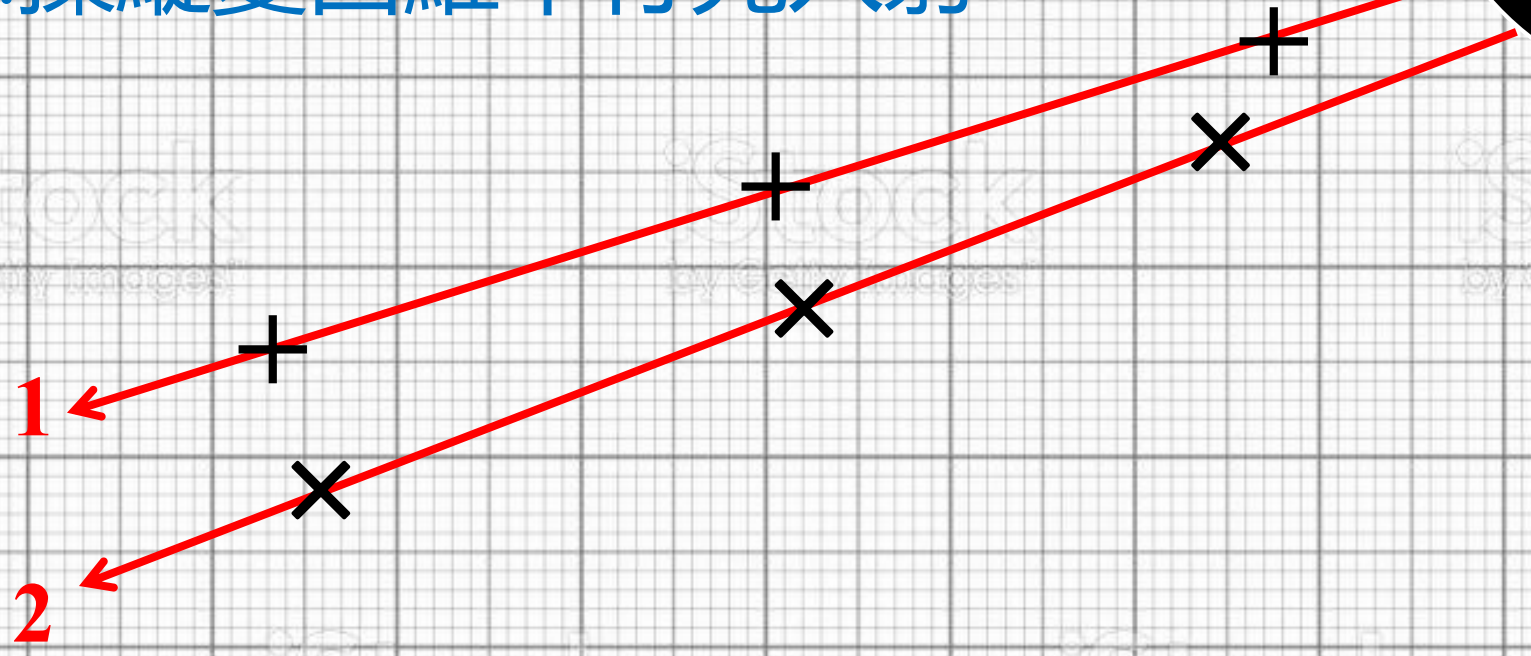


減輕負荷：

提醒:1.光路要再一平面且平行圓平面

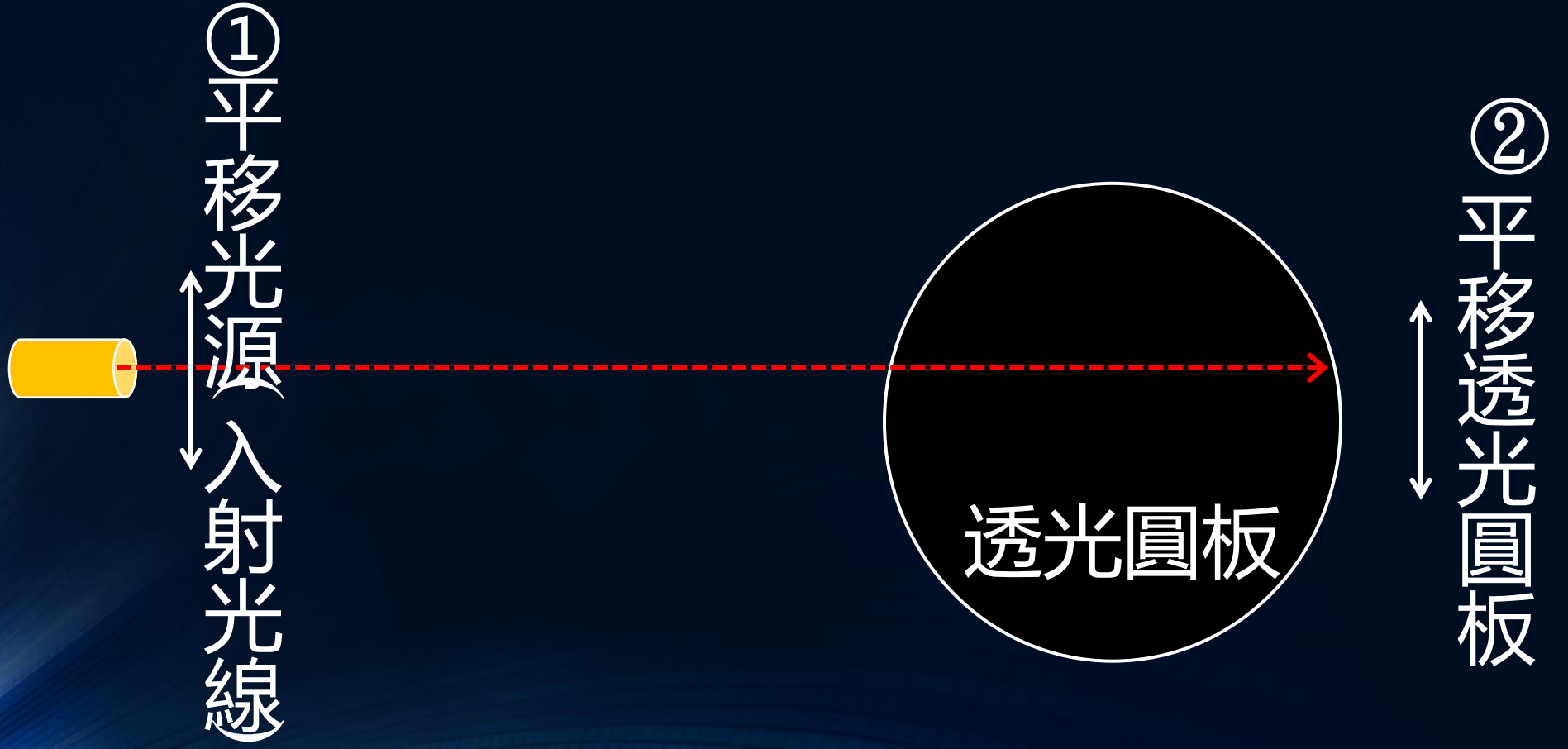


提醒:2.操縱變因維平行光入射

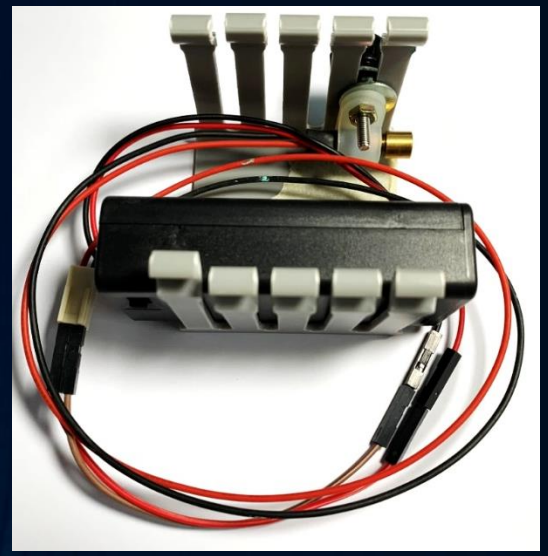


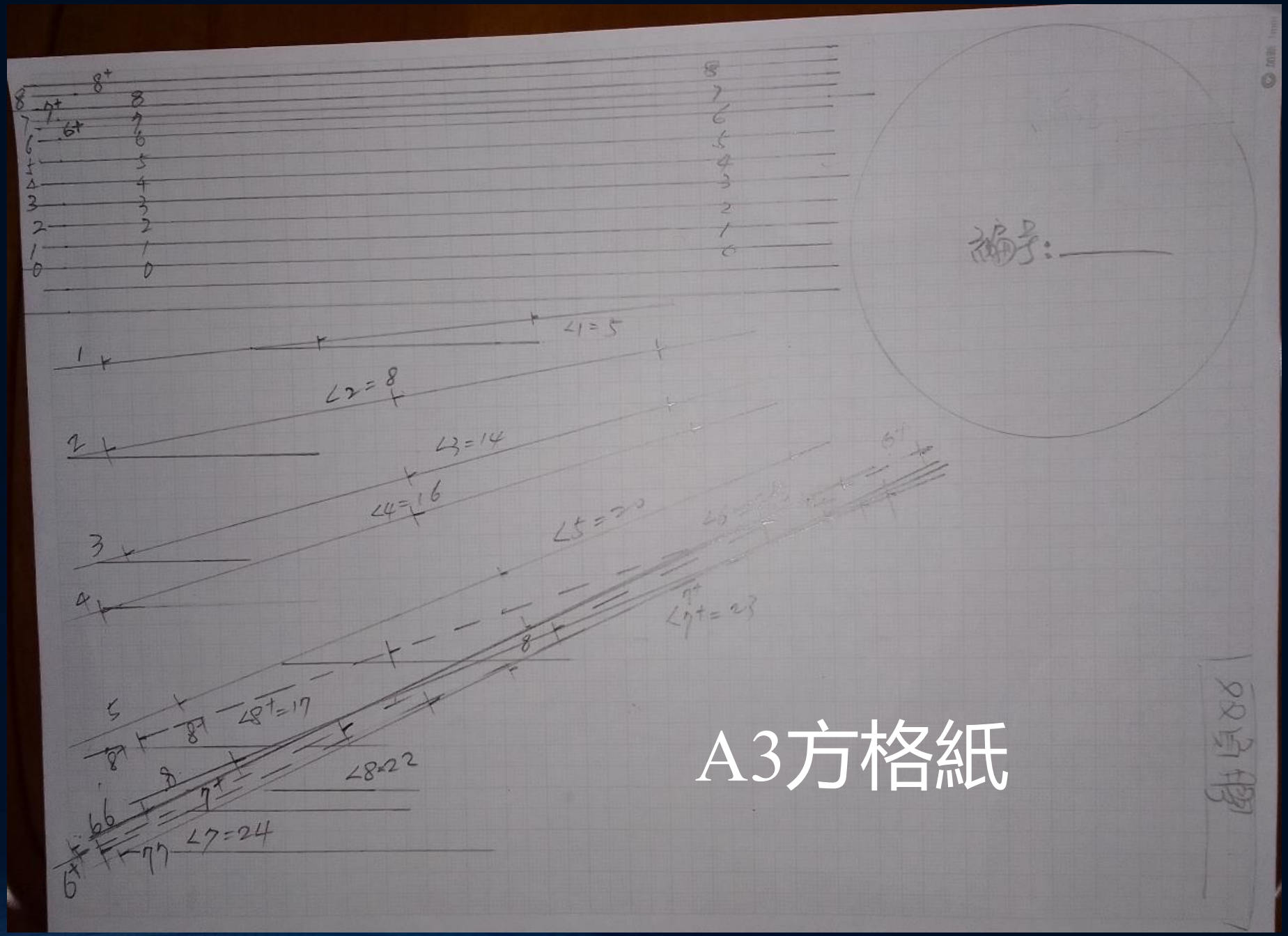
競賽編號:

減輕負荷



法①平移入射光





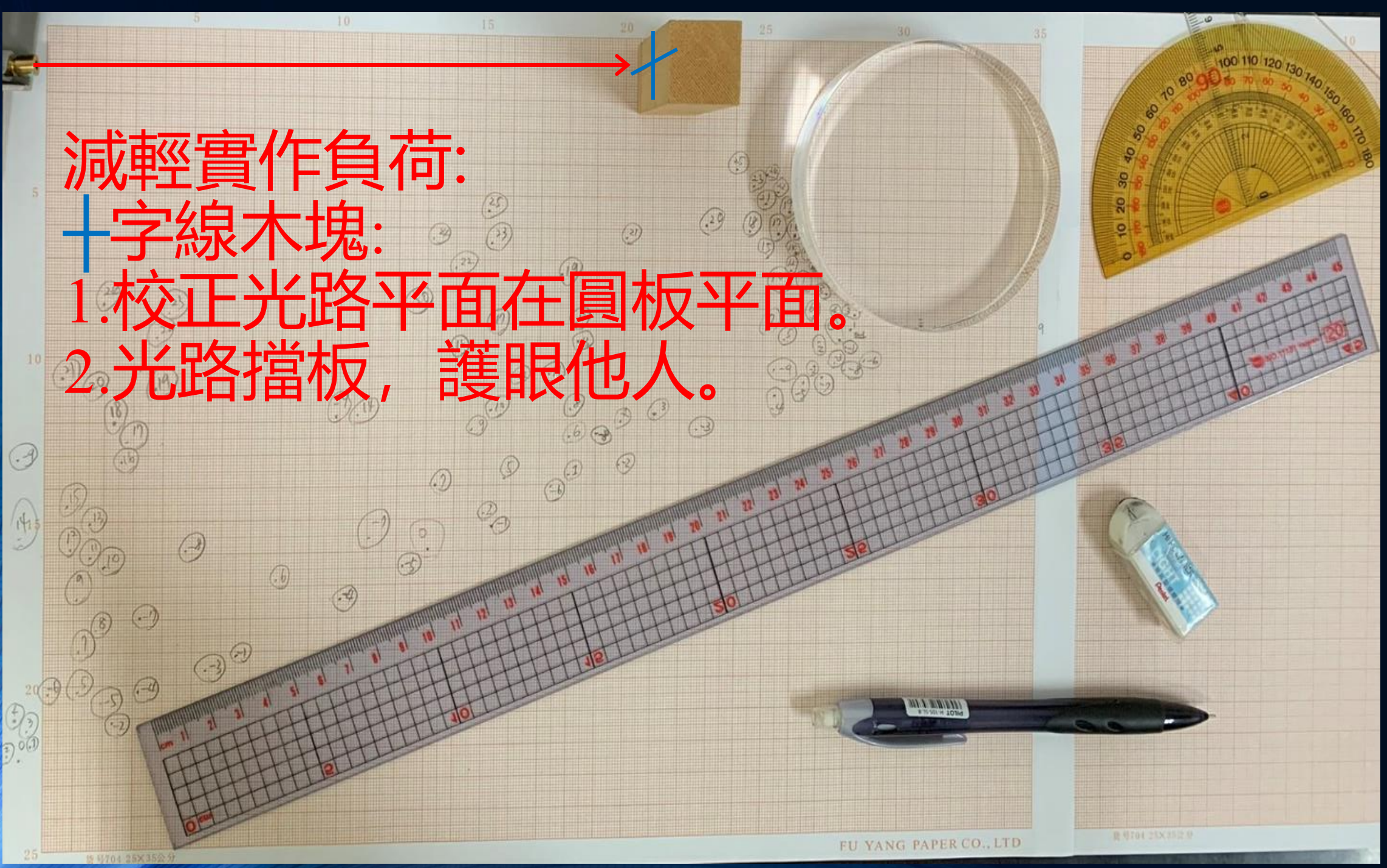
法②平移圓板

減輕實作負荷:

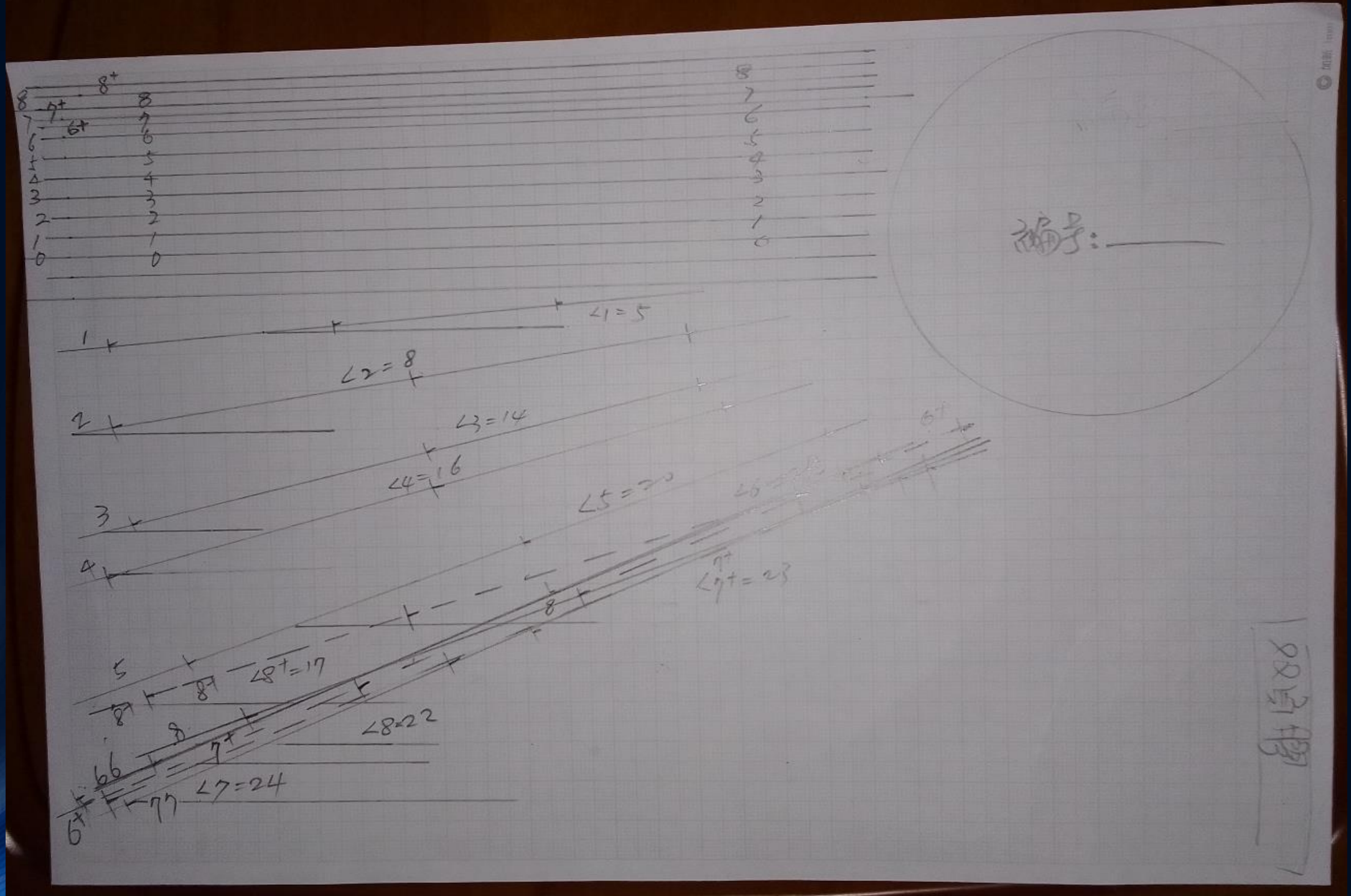
十字線木塊:

1.校正光路平面在圓板平面。

2.光路擋板，護眼他人。

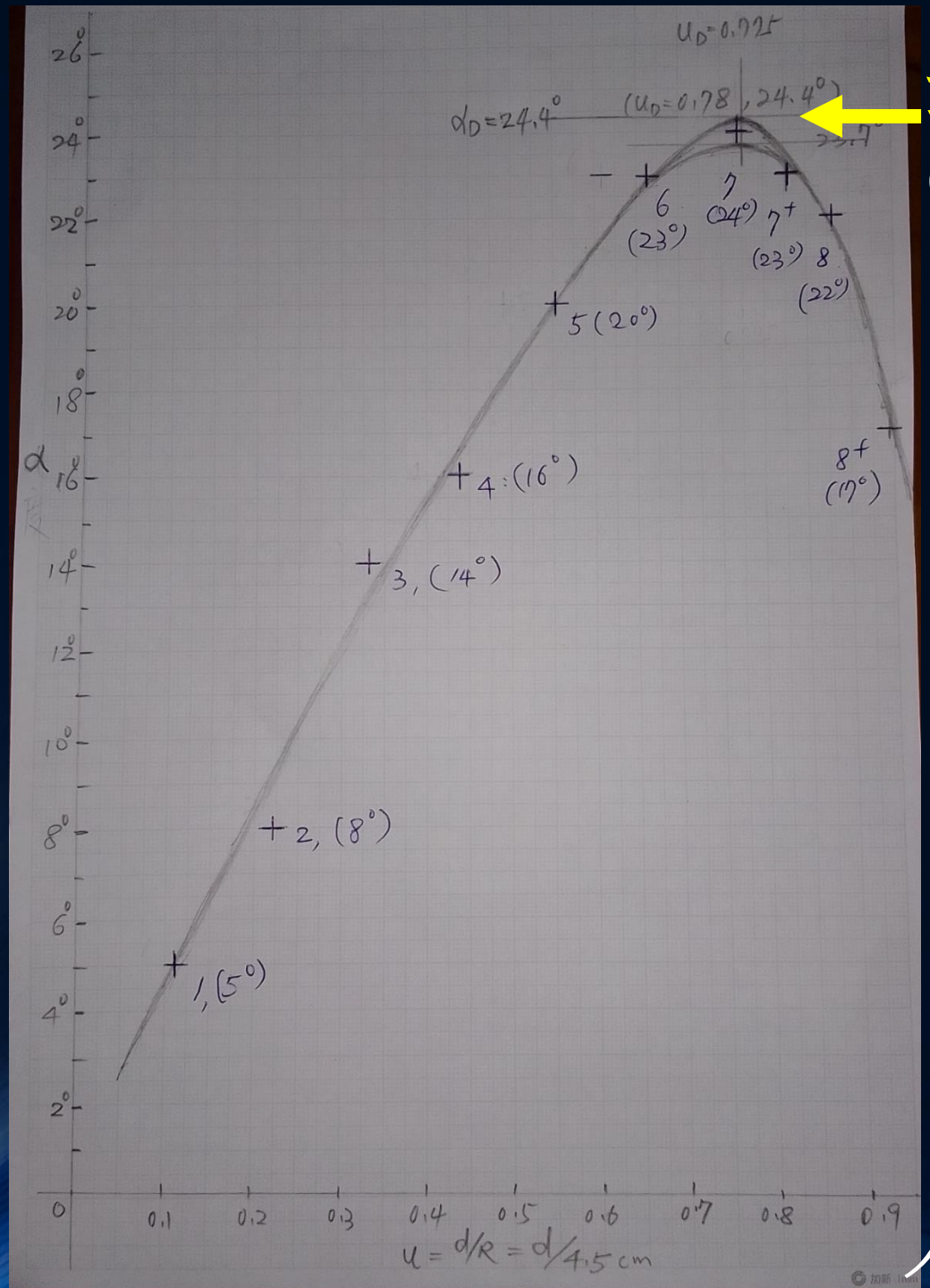


實作紀錄



數據分析

偏折角α



最密集偏折角

$\alpha_D(n)=24.4^\circ$

$$\alpha = 4sin^{-1}\left(\frac{u}{n}\right) - 2sin^{-1}u$$

入射撞擊參數u=d/R

The Physics Teacher

A Student Experiment About Rainbows: Ray Tracing Through an Acrylic Cylinder

Cite as: Phys. Teach. **59**, 692 (2021); https://doi.org/10.1119/10.0007394
Published Online: 19 November 2021

Minkyung Kim, Wonseok Kang and Jung Bog Kim

質量新標準:
從量子常數(h)　到粒子質量(m_e、m_X)

$$\frac{1}{\lambda_{vac}} = R_\infty\left(\frac{1}{n_1} - \frac{1}{n_2}\right) \qquad R_\infty = \frac{m_e e^4}{8\varepsilon_0^2 h^2} \rightarrow \boldsymbol{m_e(h)}$$

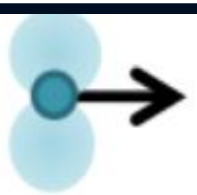
量子常數 $\boldsymbol{h}$

微小質量 m_e m_X

$$p = \frac{\boldsymbol{hf}}{c},$$
$$E = hf$$

靜止基態

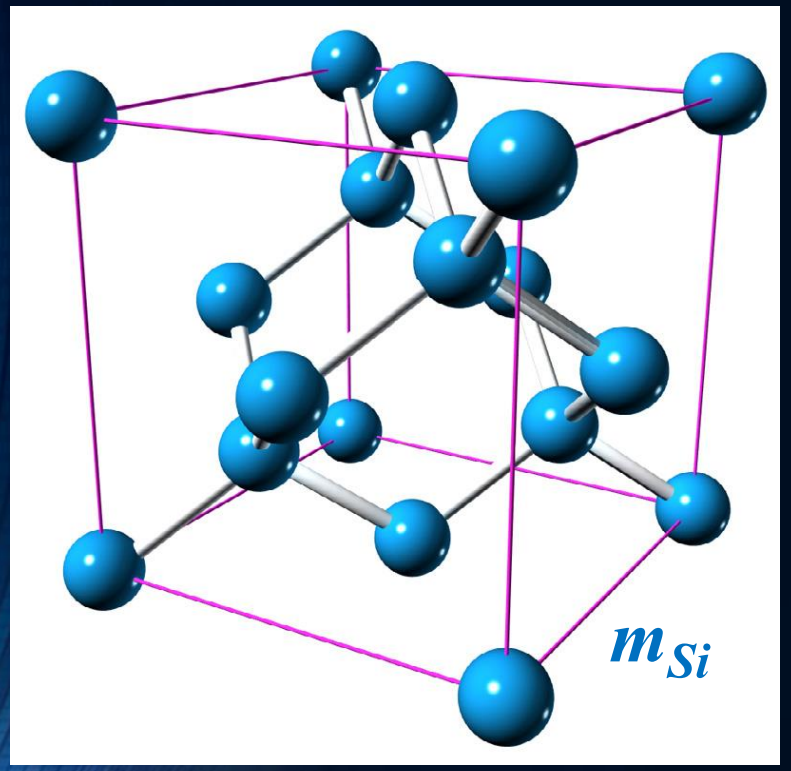
吸收光子



反退激發態

$$v_R = \frac{\boldsymbol{hf}}{\boldsymbol{m_X}c}$$

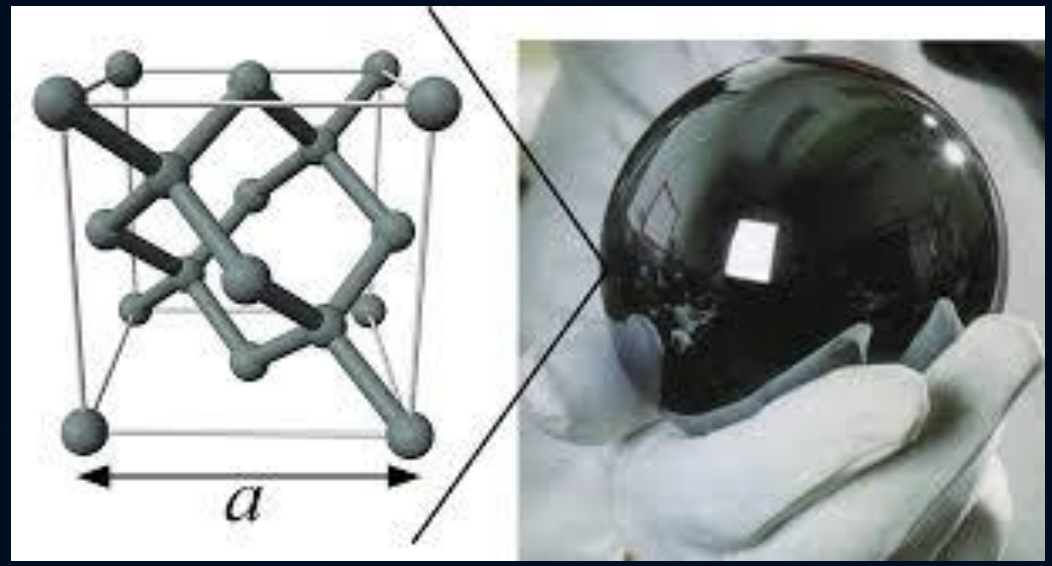
X-光 繞射 晶體密度法(XRCD)



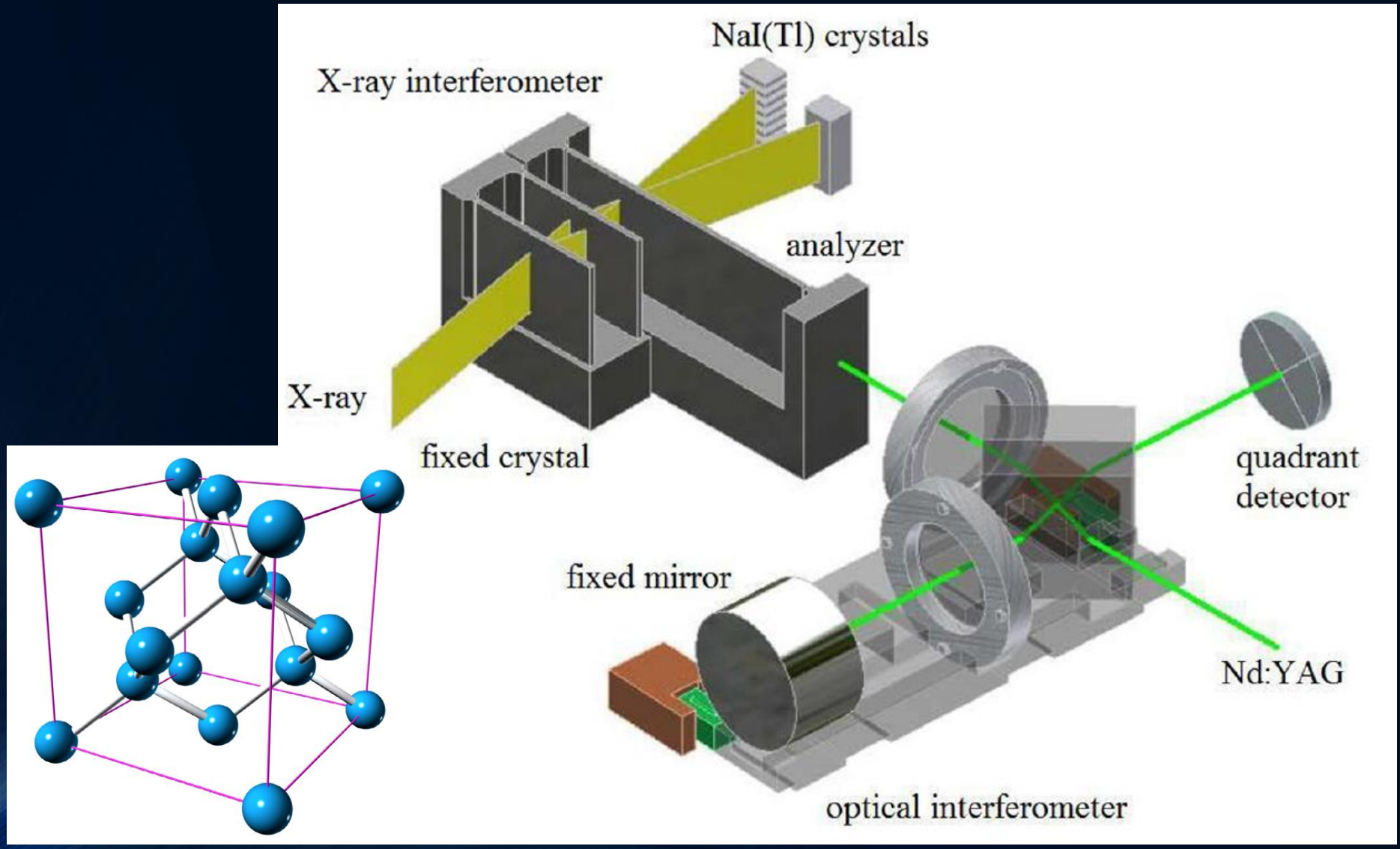
矽的單位晶格
邊常為 a，含 8 原子

微觀密度ρ_μ 等於巨觀密度ρ_m

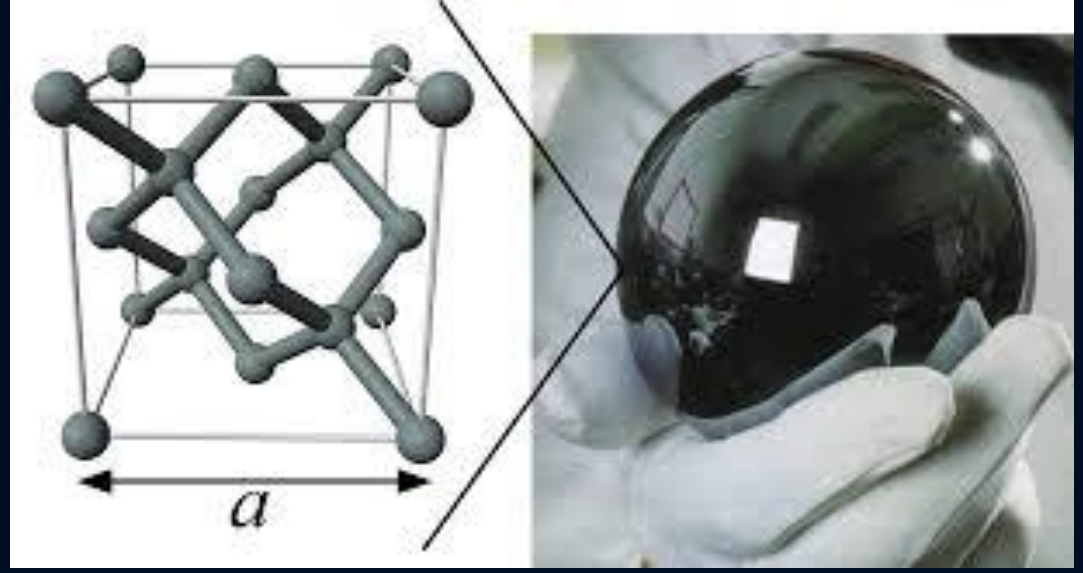
$$\rho_\mu = 8\, m_{Si} / a^3 = m / V = \rho_m.$$



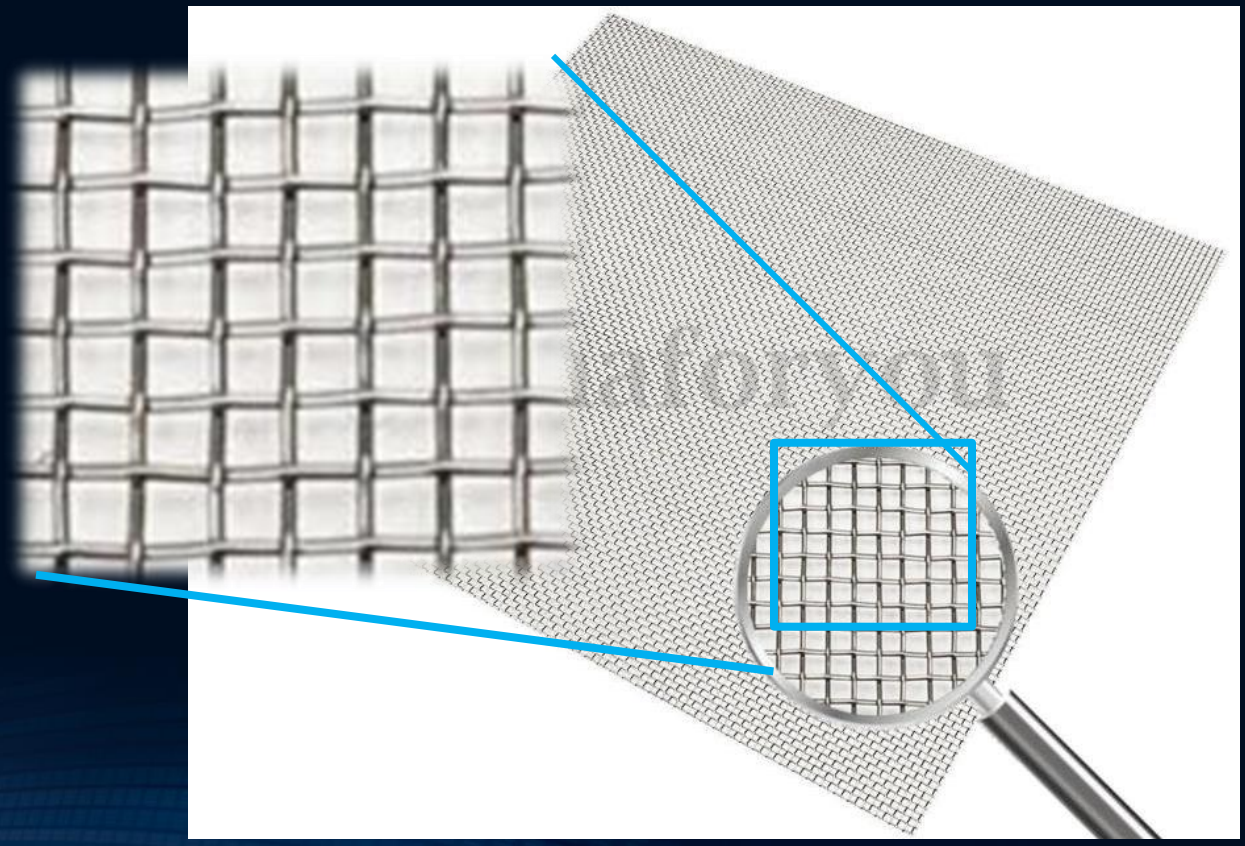
矽的單晶片 X-光繞射


NaI(Tl) crystals
X-ray interferometer
analyzer
X-ray
fixed crystal
quadrant
detector
fixed mirror
Nd:YAG
optical interferometer

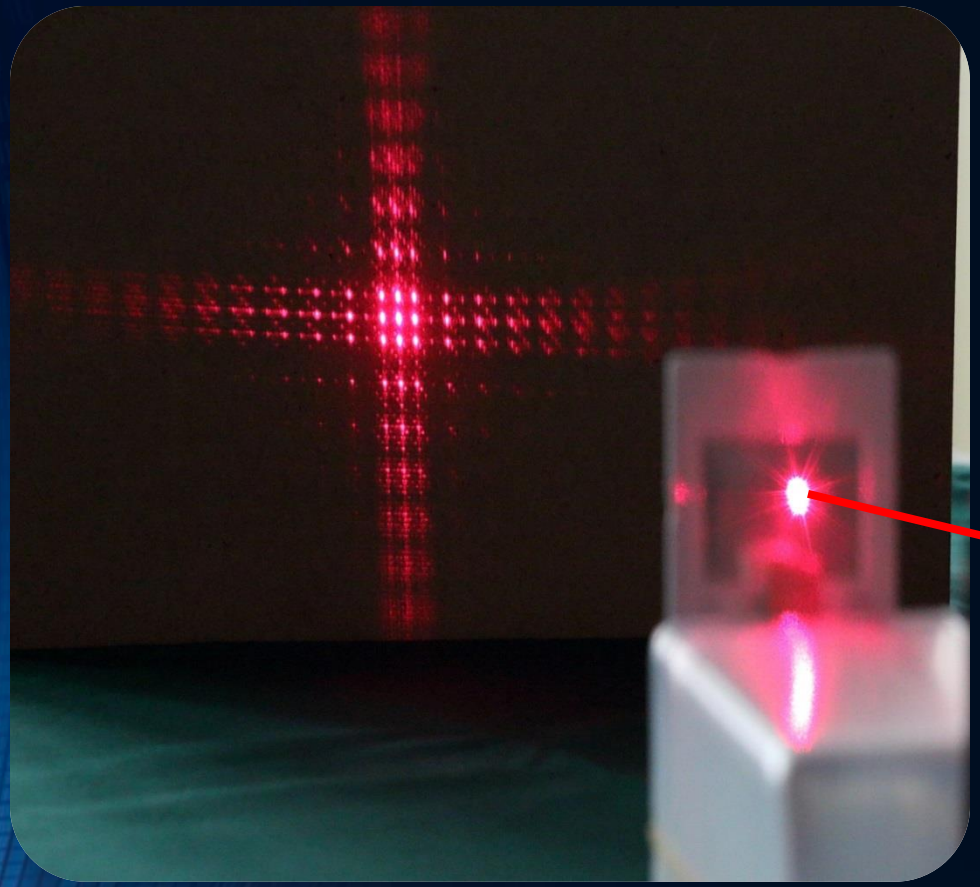
3維 Si 晶格
x 光繞射
測量晶格寬a

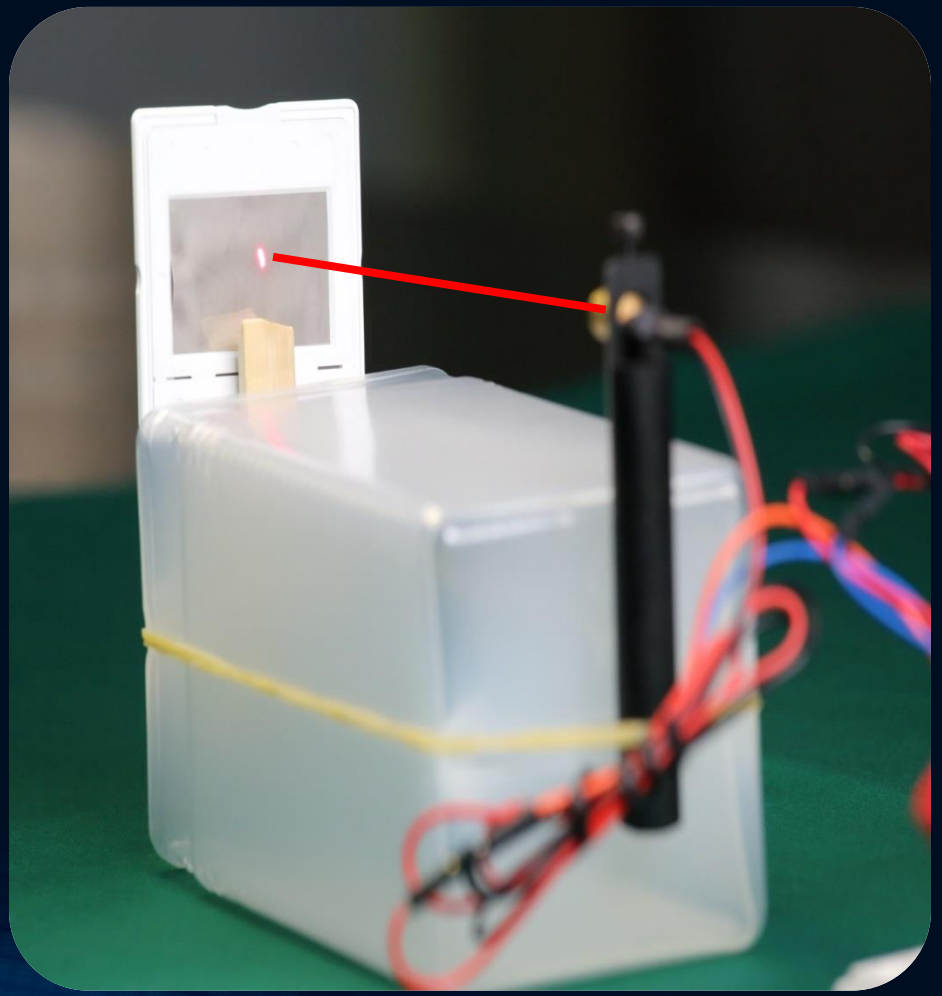


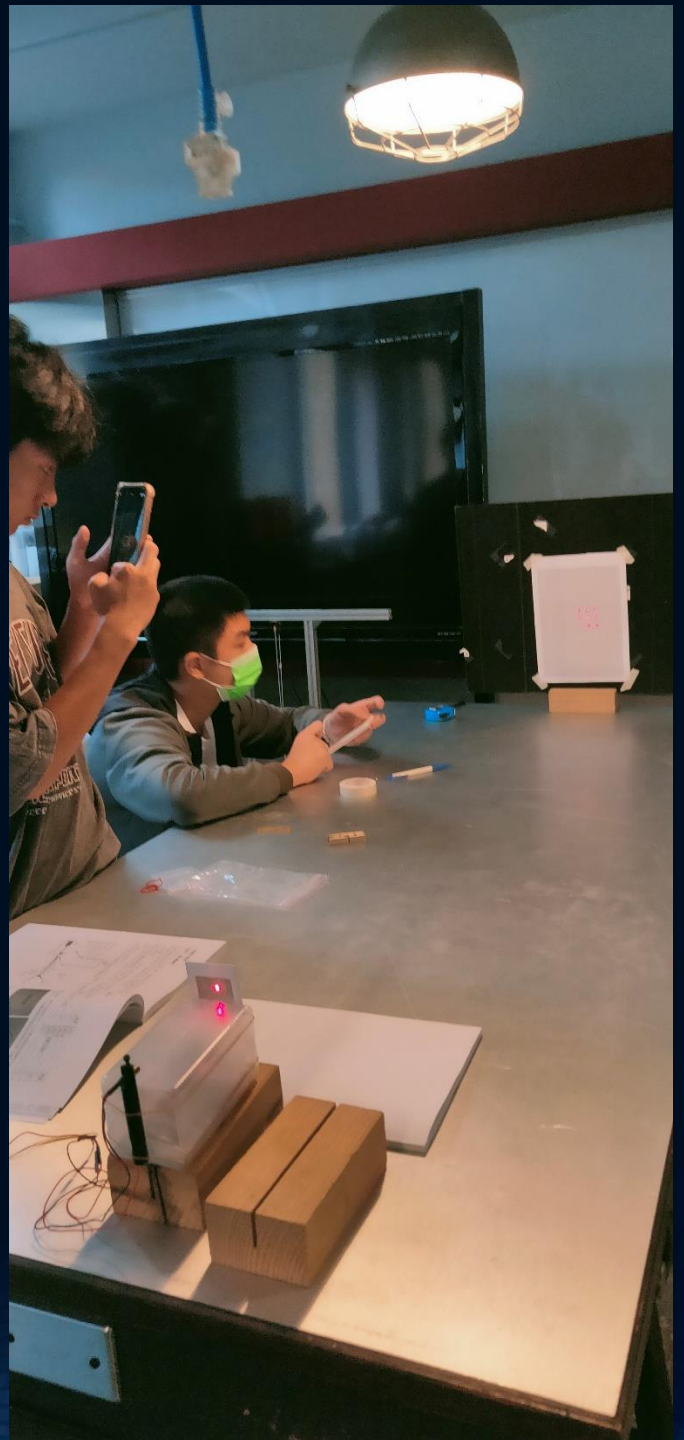
2維鋼絲網格
可見光繞射
測量網格寬 d

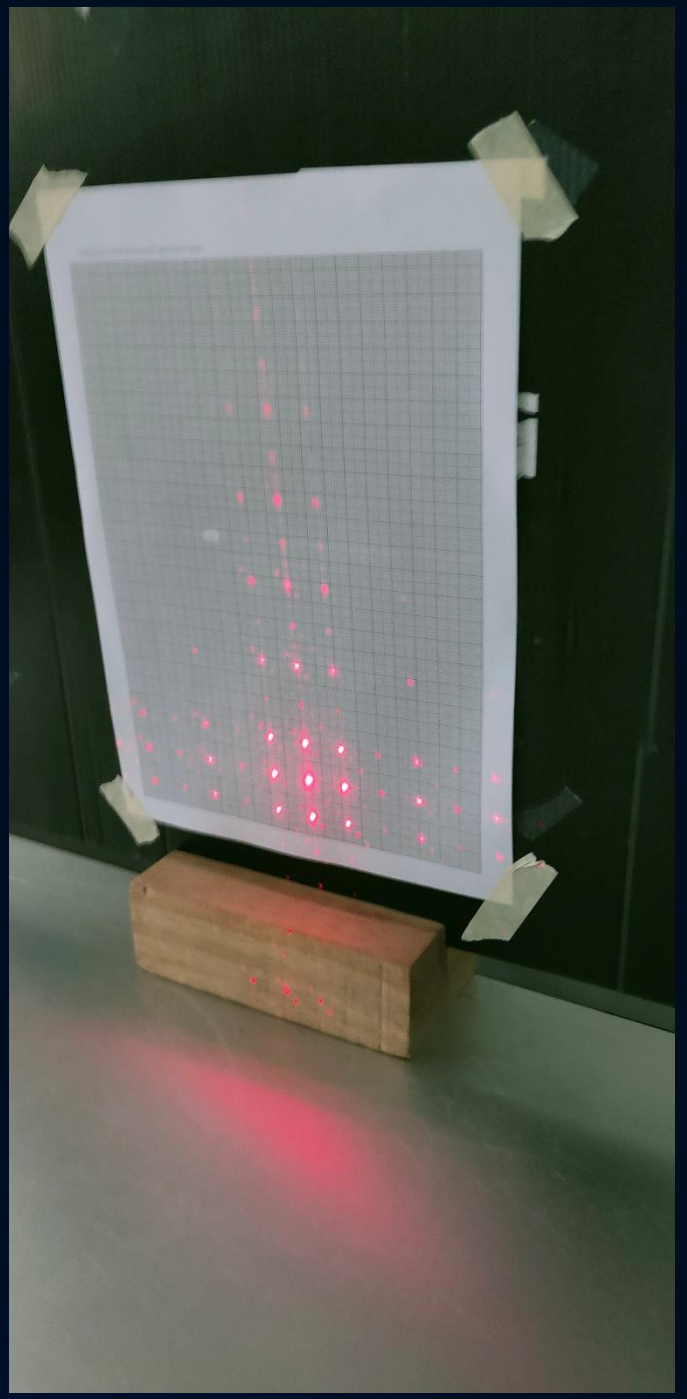


網格繞射



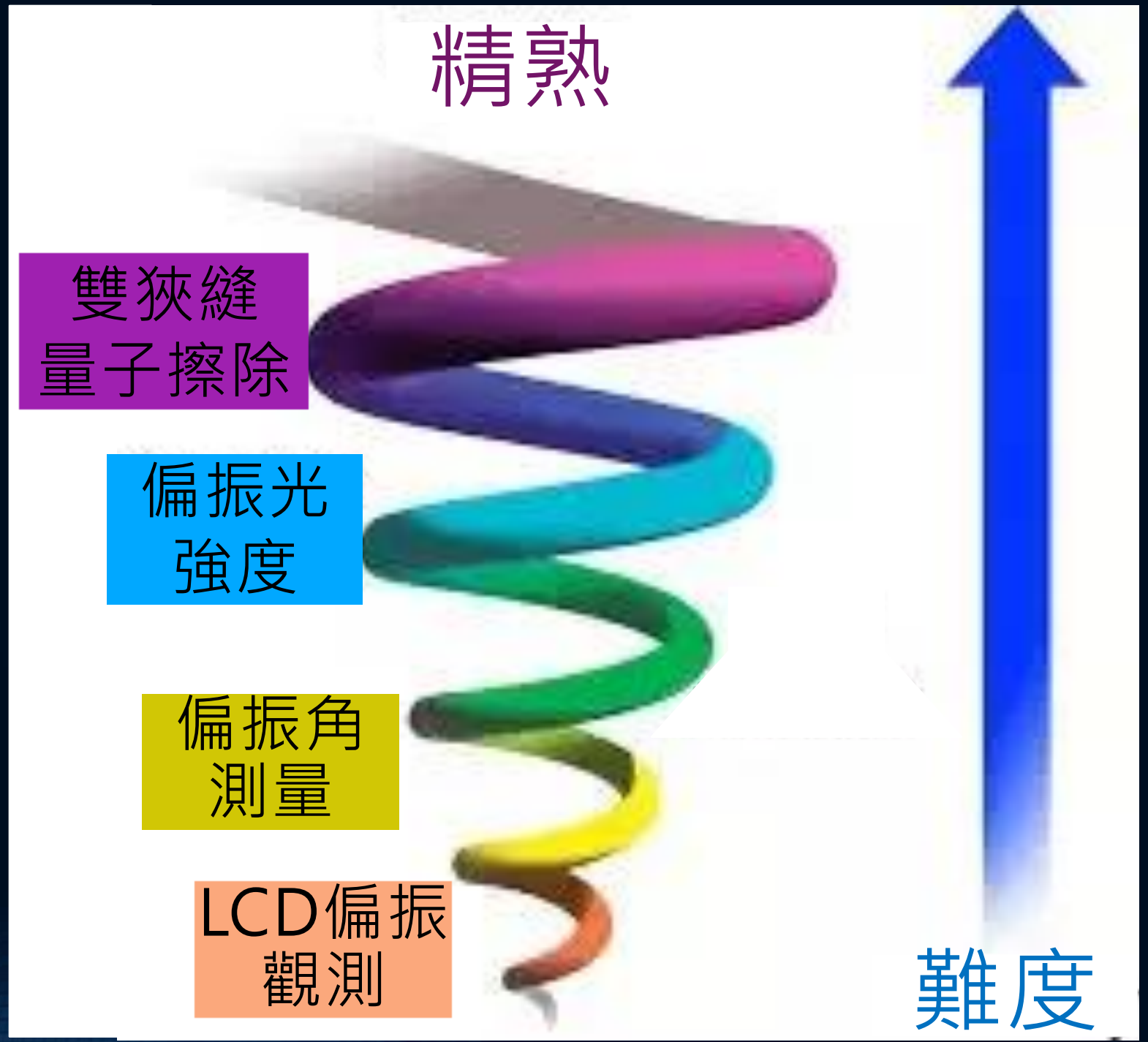






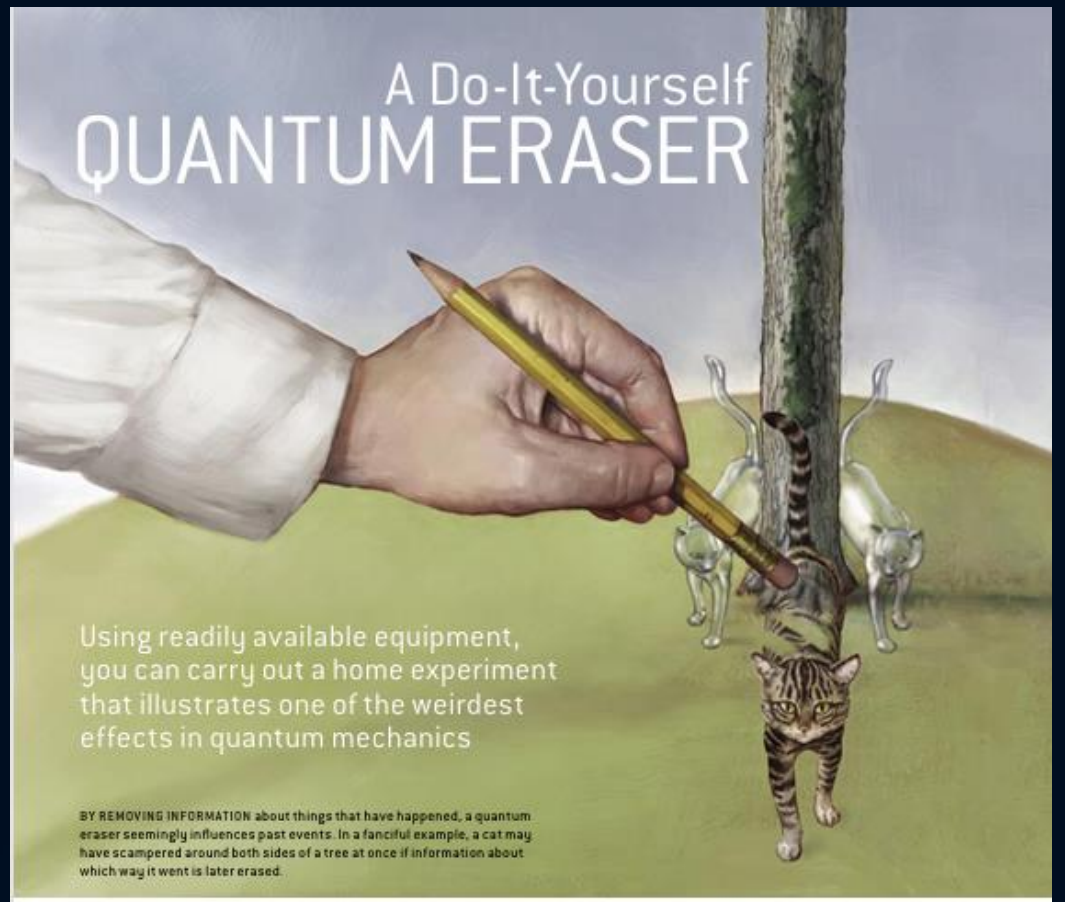
光偏振之波動與量子探究

4模組
循序漸進



DIY社群

Scientific American



A Do-It-Yourself QUANTUM ERASER

Using readily available equipment, you can carry out a home experiment that illustrates one of the weirdest effects in quantum mechanics

BY REMOVING INFORMATION about things that have happened, a quantum eraser seemingly influences past events. In a fanciful example, a cat may have scampered around both sides of a tree at once if information about which way it went is later erased.

BY RACHEL HILLMER AND PAUL KWIAT

Notoriously, the theory of quantum mechanics reveals a fundamental weirdness in the way the world works. Commonsense notions at the very heart of our everyday perceptions of reality turn out to be violated: contradictory alternatives can coexist, such as an object following two different paths at the same time; objects do not simultaneously have precise positions and velocities; and the properties of objects and events we observe can be subject to an ineradicable randomness that has nothing to do with the imperfection of our tools or our eyesight.

Gone is the reliable world in which atoms and other particles travel around like well-behaved billiard balls on the green baize of reality. Instead they behave (sometimes) like waves, becoming dispersed over a region and capable of criss-crossing to form interference patterns.

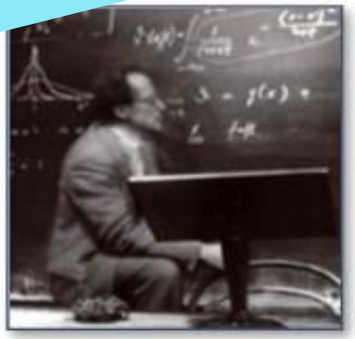
Yet all this strangeness still seems remote from ordinary life. Quantum effects are most evident when tiny systems are involved, such as electrons held within the confines of an atom. You might know in the abstract that quantum phenomena underlie most modern technologies and that various quantum oddities can be demonstrated in laboratories, but the only way to see them in the home is on science shows on television. Right? Not quite.

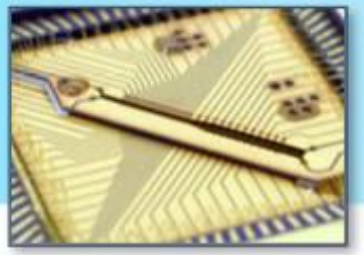
On pages 92 and 93, we will show you how to set up an experiment that illustrates what is known as quantum erasure. This effect involves one of the oddest features of quantum mechanics—the ability to take actions that change our basic interpretation of what happened in past events.

Before we explain what we mean by that and outline the experiment itself, we do have to emphasize one caveat in the

大處著眼: 量子革命方興未艾

回到教室：奠定基礎
小處著手 → → → → → 大處著眼





第一次
量子革命

量子論
波粒二象性
能級與躍遷

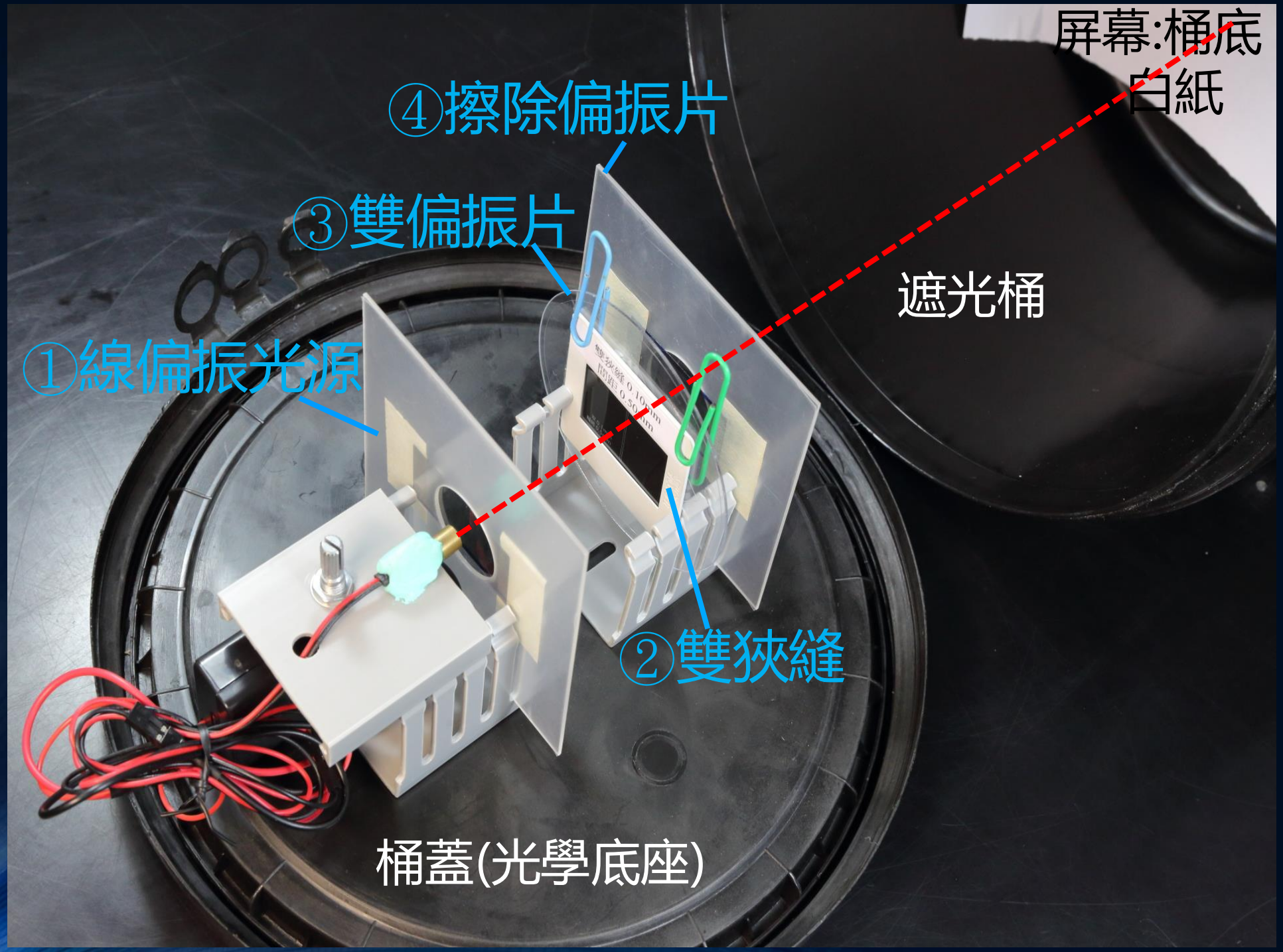
第三次
科技(產業)革命

物質微觀模型與應用
操弄原子團、簇、線、層
積體電路
雷射
發光二極體
原子彈、核能..

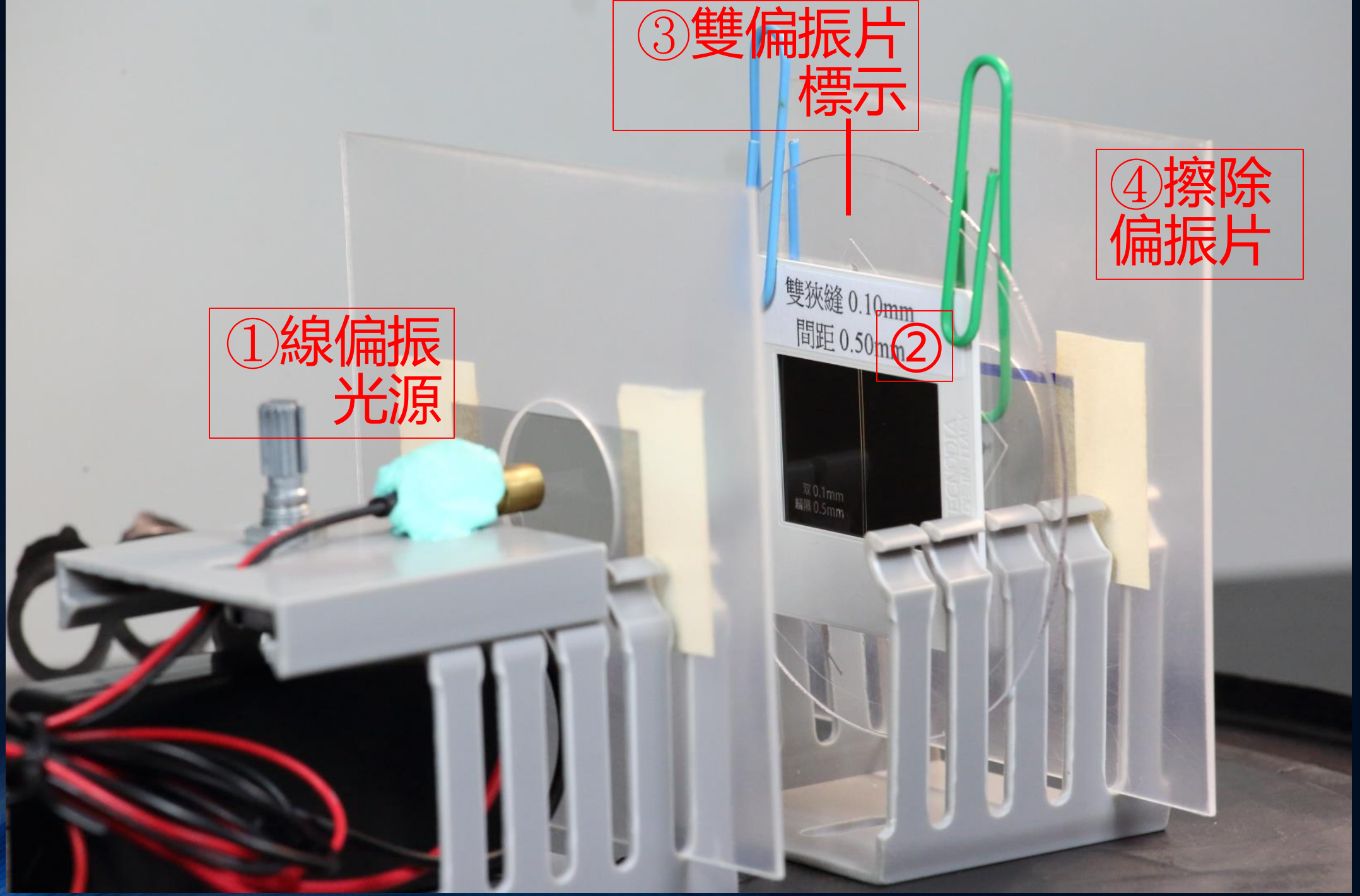
第二次
量子革命

操弄量子態
運用量子現象:疊加...
量子演算
量子加密
量子通訊
量子AI
量子電腦
量子化學
量子生醫
...

量子擦除裝置全圖



光學元件

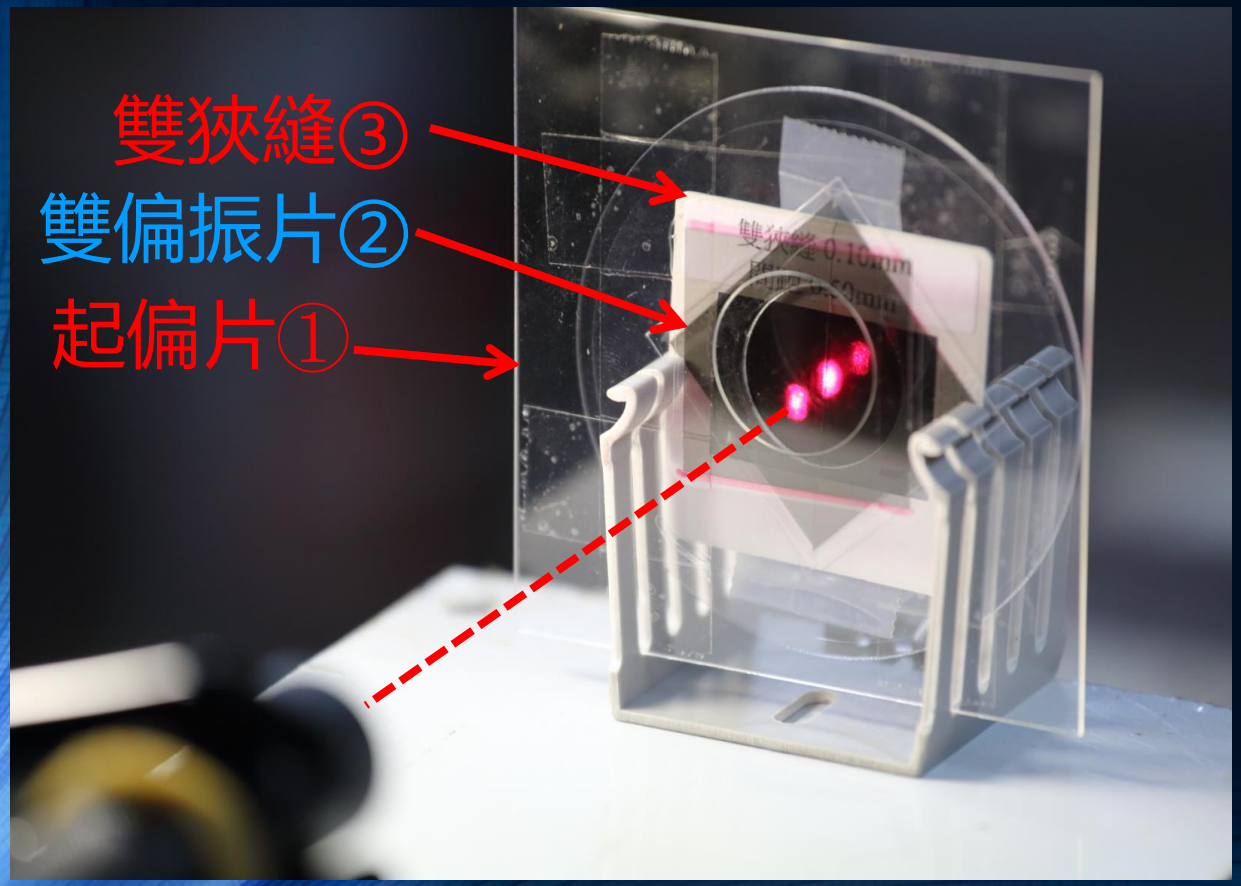


量子辨識(辨認、標示)

雙偏振片②

→ 標示通過狹縫

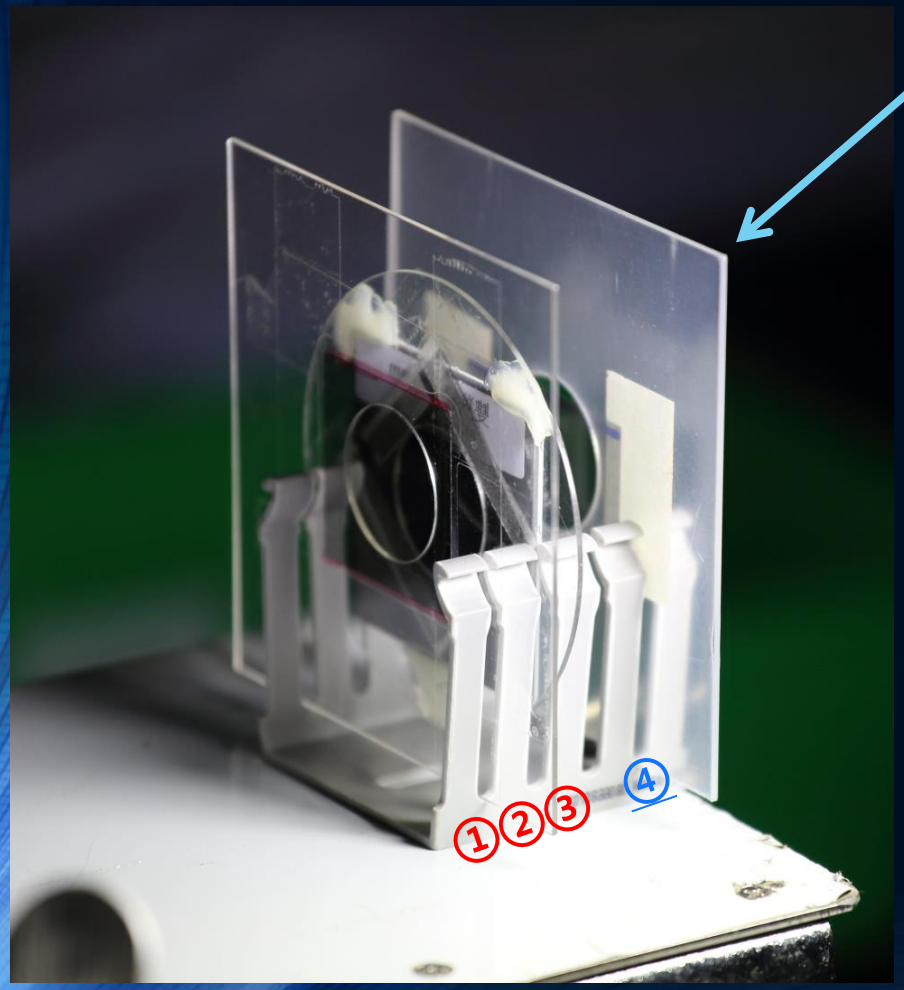
→ 雙狹縫疏密分布消失



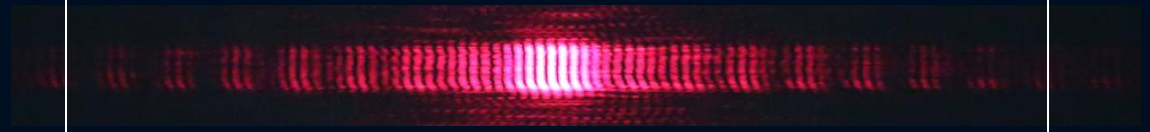
經雙偏振片辨識狹縫

雙狹縫疏密分布消失

量子擦除:
(雙偏振標示①②③)+ ④↔檢偏片擦除標示



再經④檢偏片擦除標示



雙狹縫疏密分布再現

Hamamatsu, Photon Terrace (光子庭院)

開放資源

Photon terrace - Let's think abc

photonterrace.net/en/

Google | Yahoo奇摩 | Complicated Syno... | Science : Educatio... | SPICE - a brief ove... | 學術研發服務網 | Skeeter Davis's Gr... | google | 科技部人文社會科... | 物理學系

Let's learn about Light

Photon terrace™

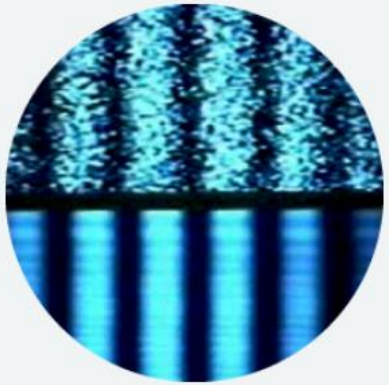
Produced by HAMAMATSU

Concept | Japanese | English | ENHANCED BY Google

Nature of light | Light-based technology | Applications of light | Professor lights | Photon Boy adventure | Photon lab.

Learn about light -A wave but also a particle!? Wonders of light-

Though light plays a vital role in forming our universe, there are a lot of things we still don't know about it.
At certain times it behaves like a wave, at certain times like a particle.
Let's start learning the wonderful properties of light.



The basic nature of light

Light is a wonderful substance having many unique characteristics. Let's come one step closer to the wonders of light through well-known basic properties.

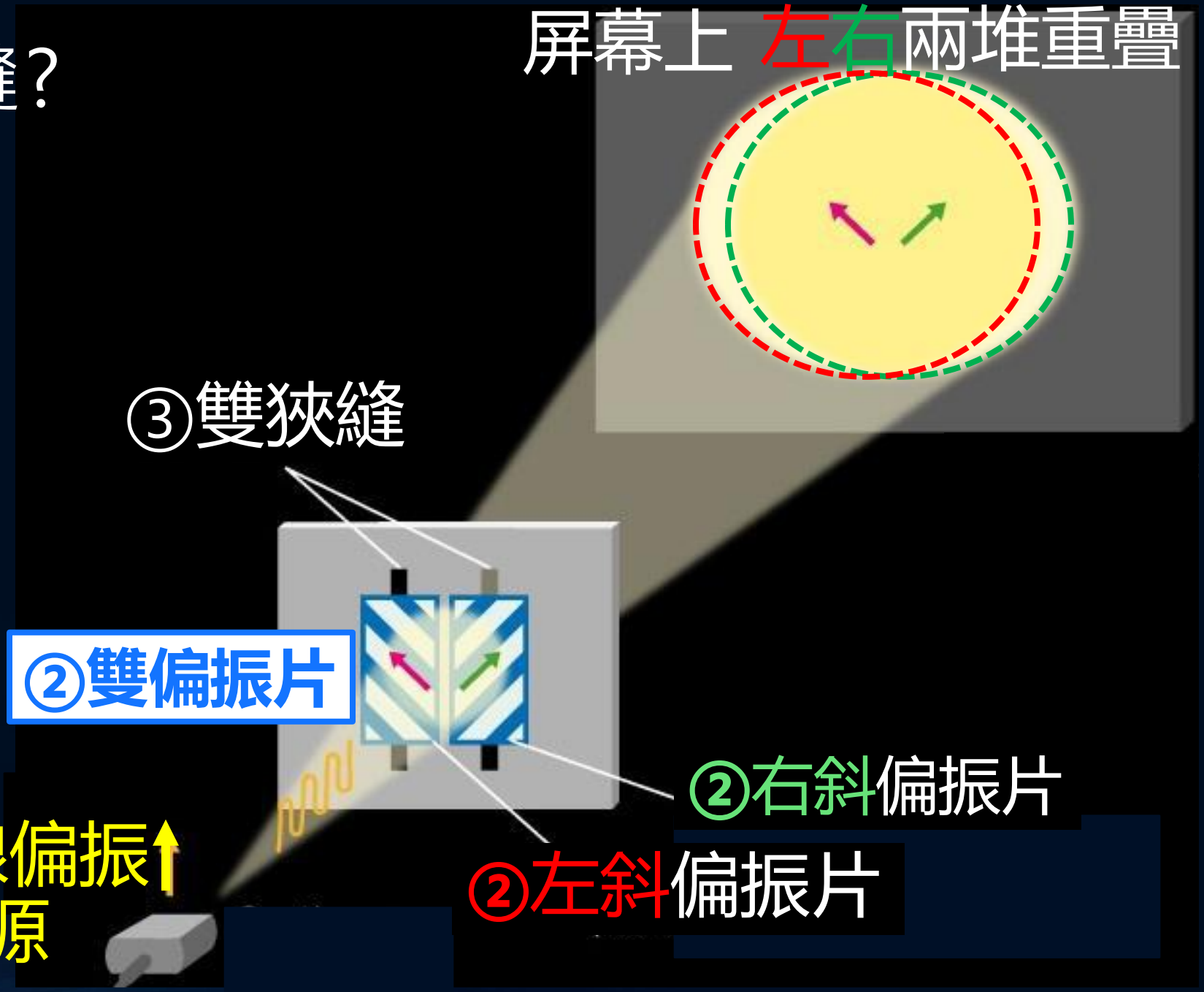
State of light

The light that we see with our eyes is actually just a part of the "light" family. Let's take a look at the figures of light focusing on "wavelength" and "brightness".

History of research on light

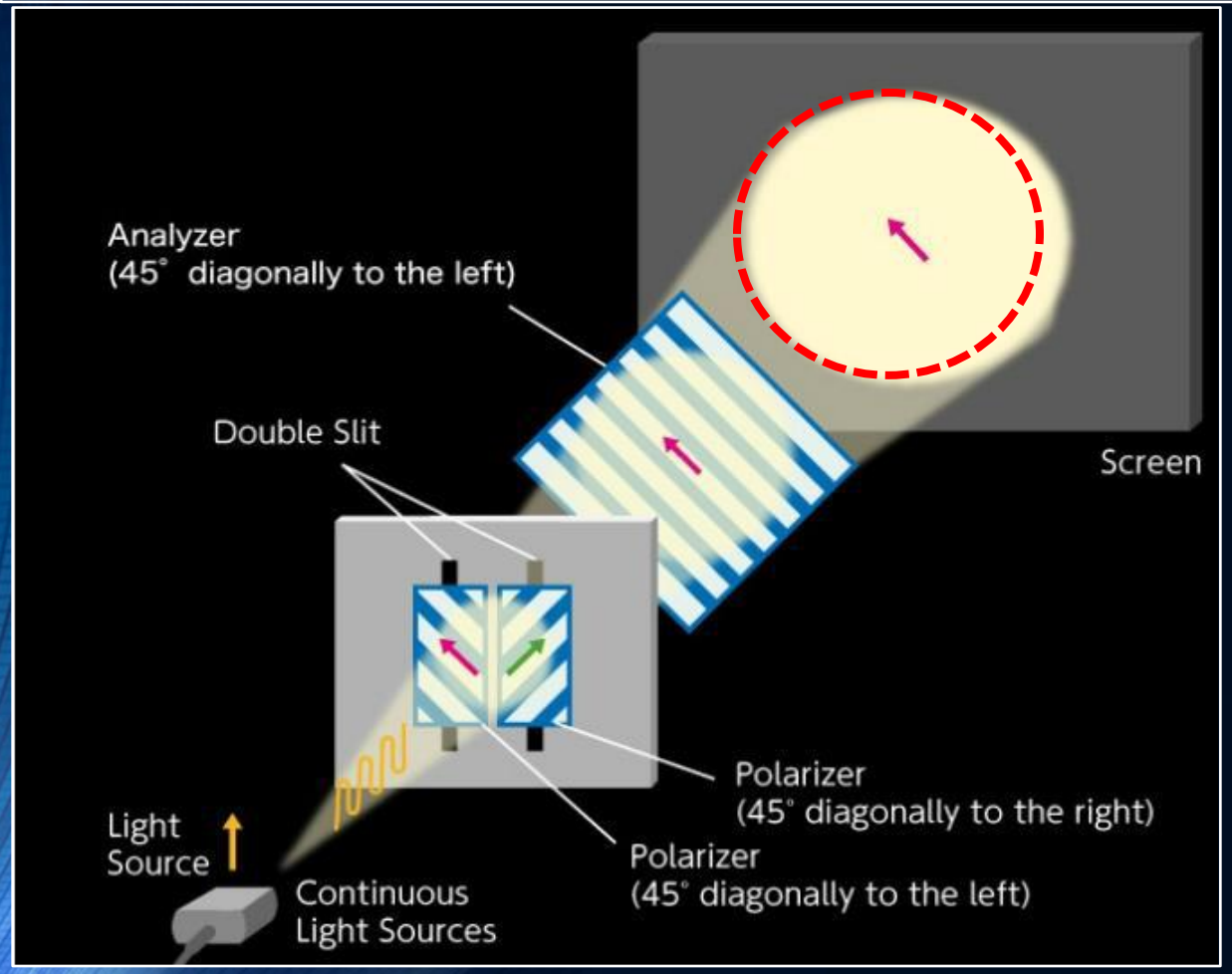
Many researchers throughout the ages have taken up the challenge of finding out "What is Light?" The history of light research which is closely related with the growth of science and

辨識光子通過狹縫?
利用偏振

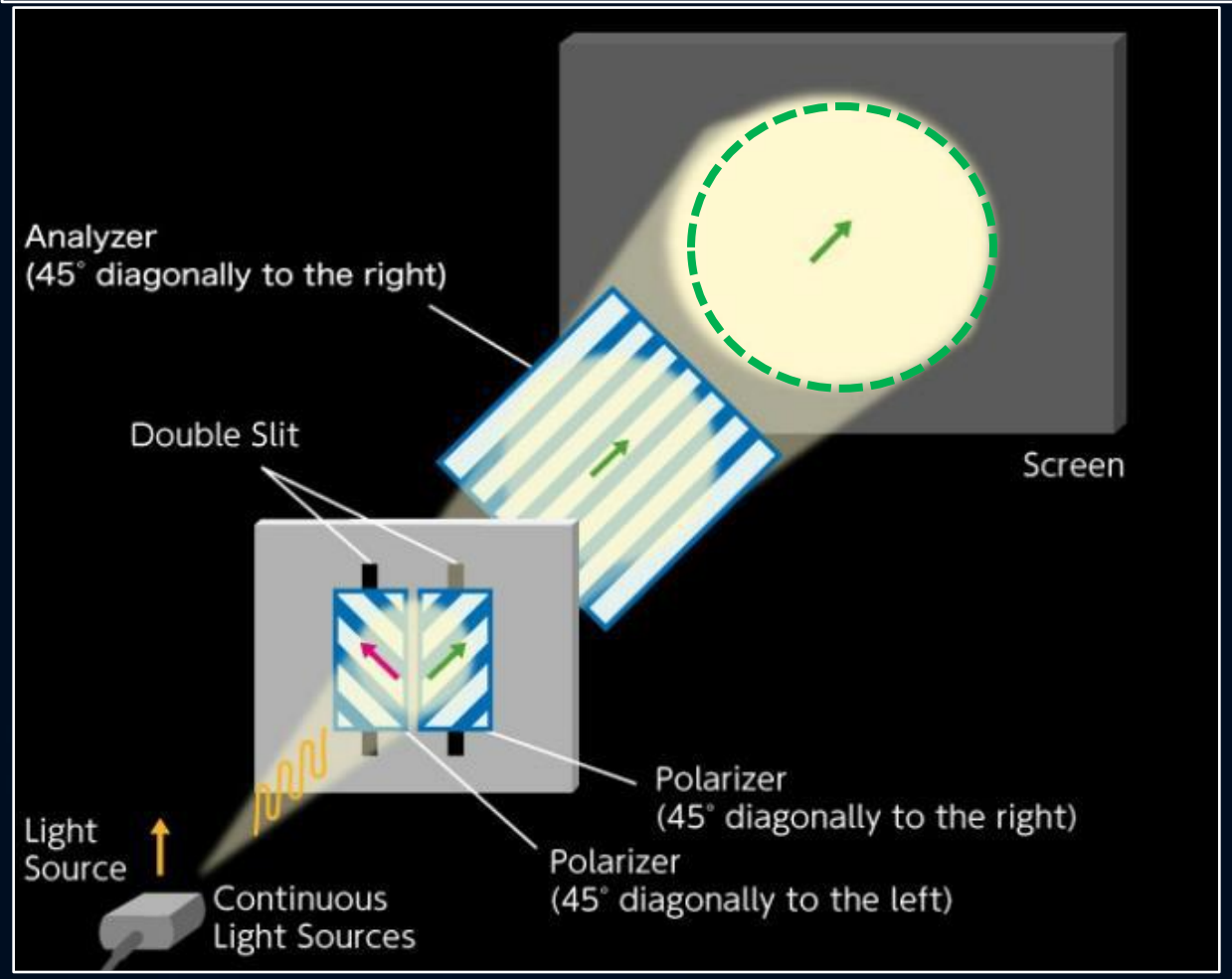


Hamamatsu,
Photon Terrace,
https://photonterrace.net/en/photon/single_p

左斜偏振辨識通過左狹縫全粒不發生干涉



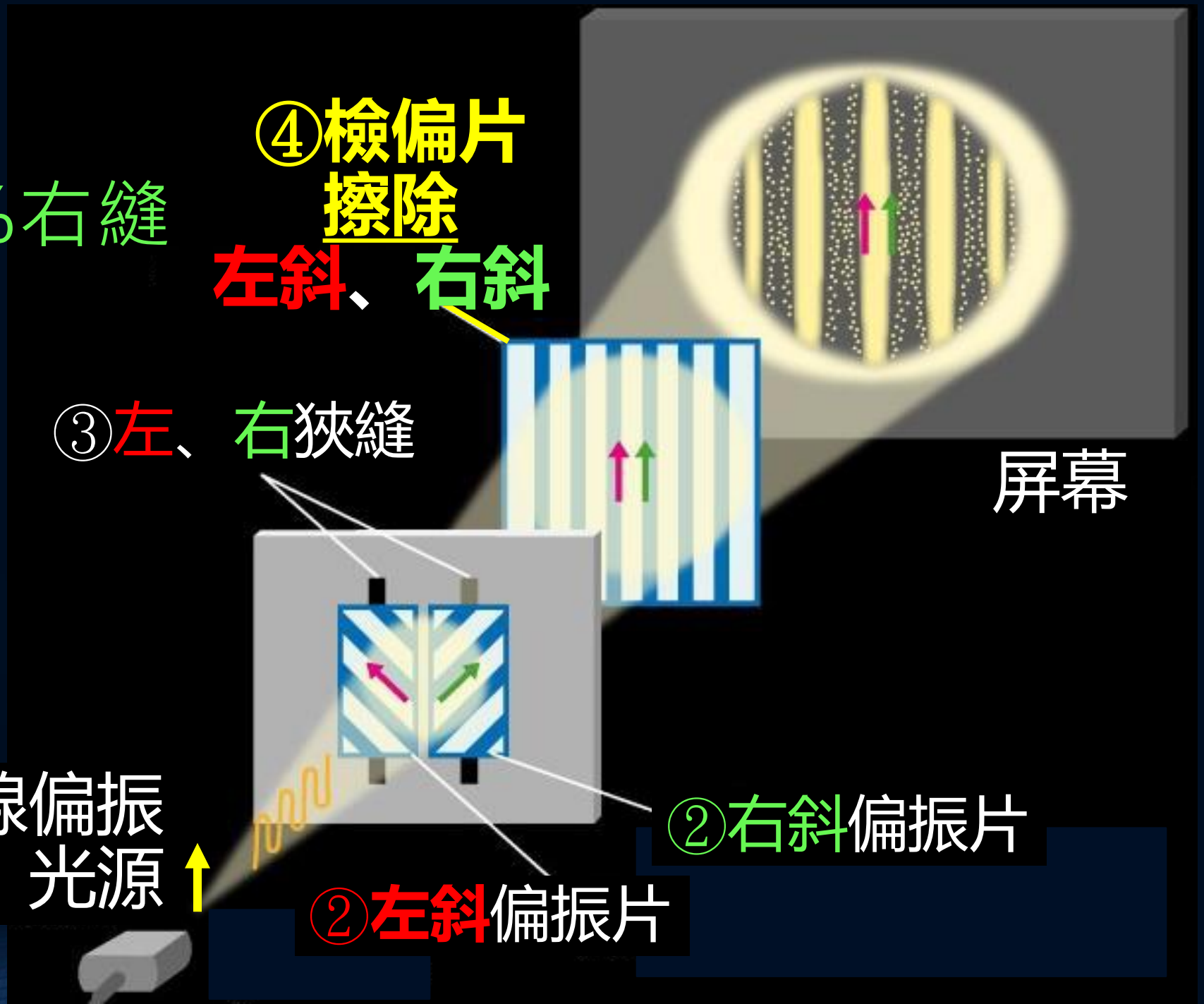
右斜偏振辨識通過右狹縫全粒不發生干涉



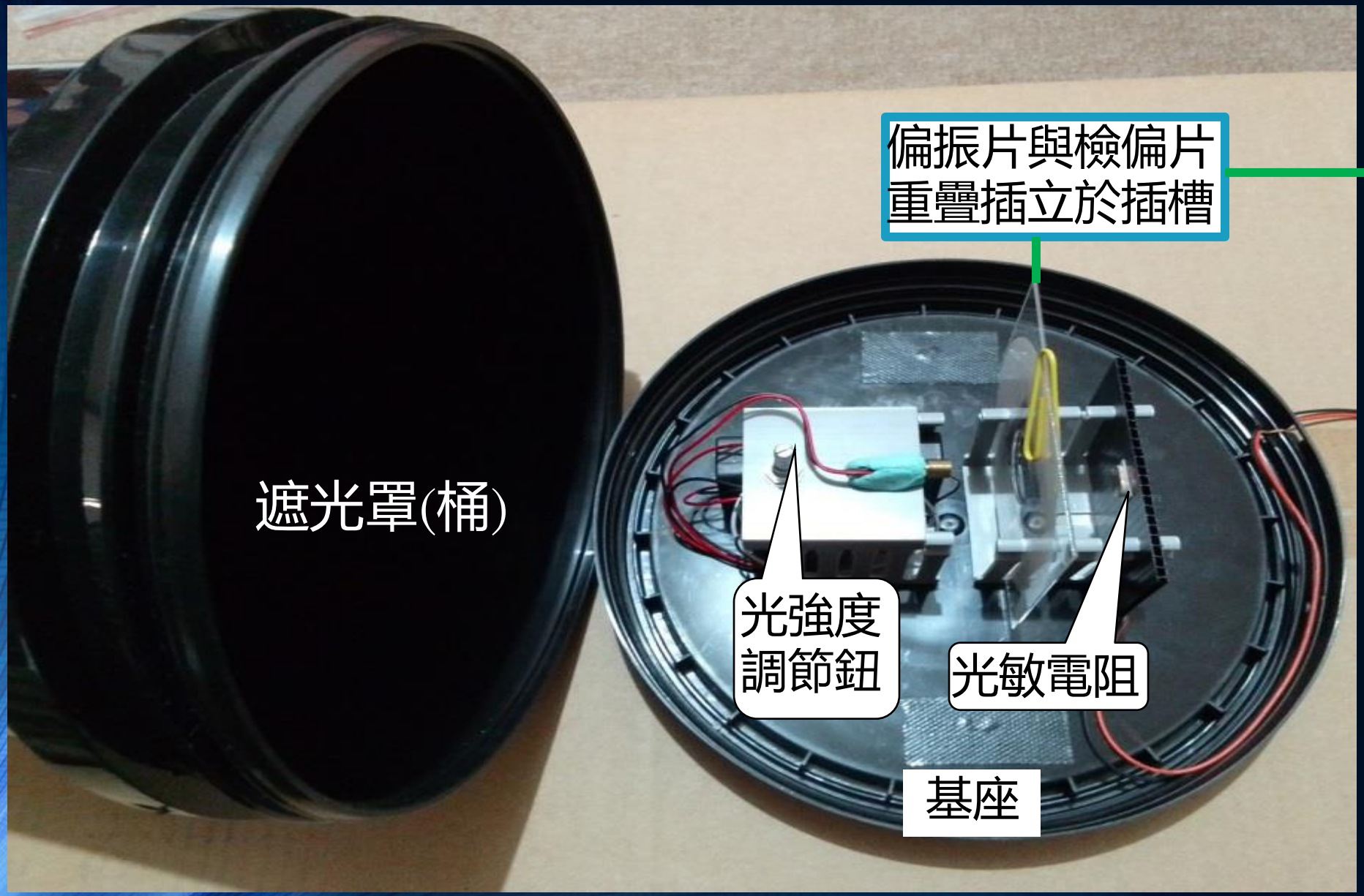
Hamamatsu, Photon Terrace,
https://photonterrace.net/en/photon/single_photon/

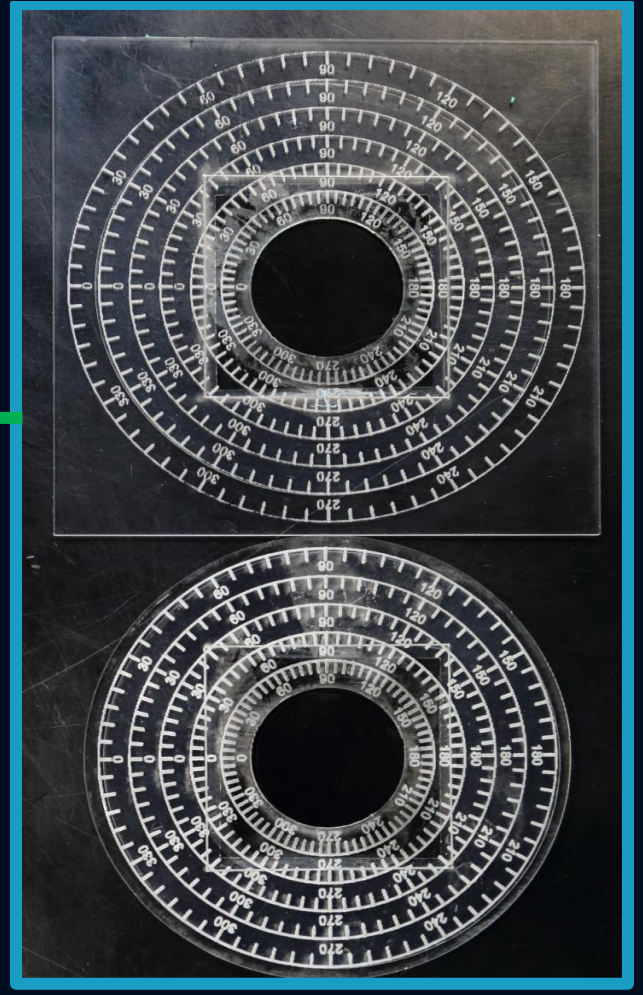
檢偏片量子擦除

通過狹縫訊息
50%左縫 & 50%右縫
疊加干涉



光偏振強度 VS. 檢偏片夾角:





光偏振強度Ｖｓ.檢偏片夾角

陽春版

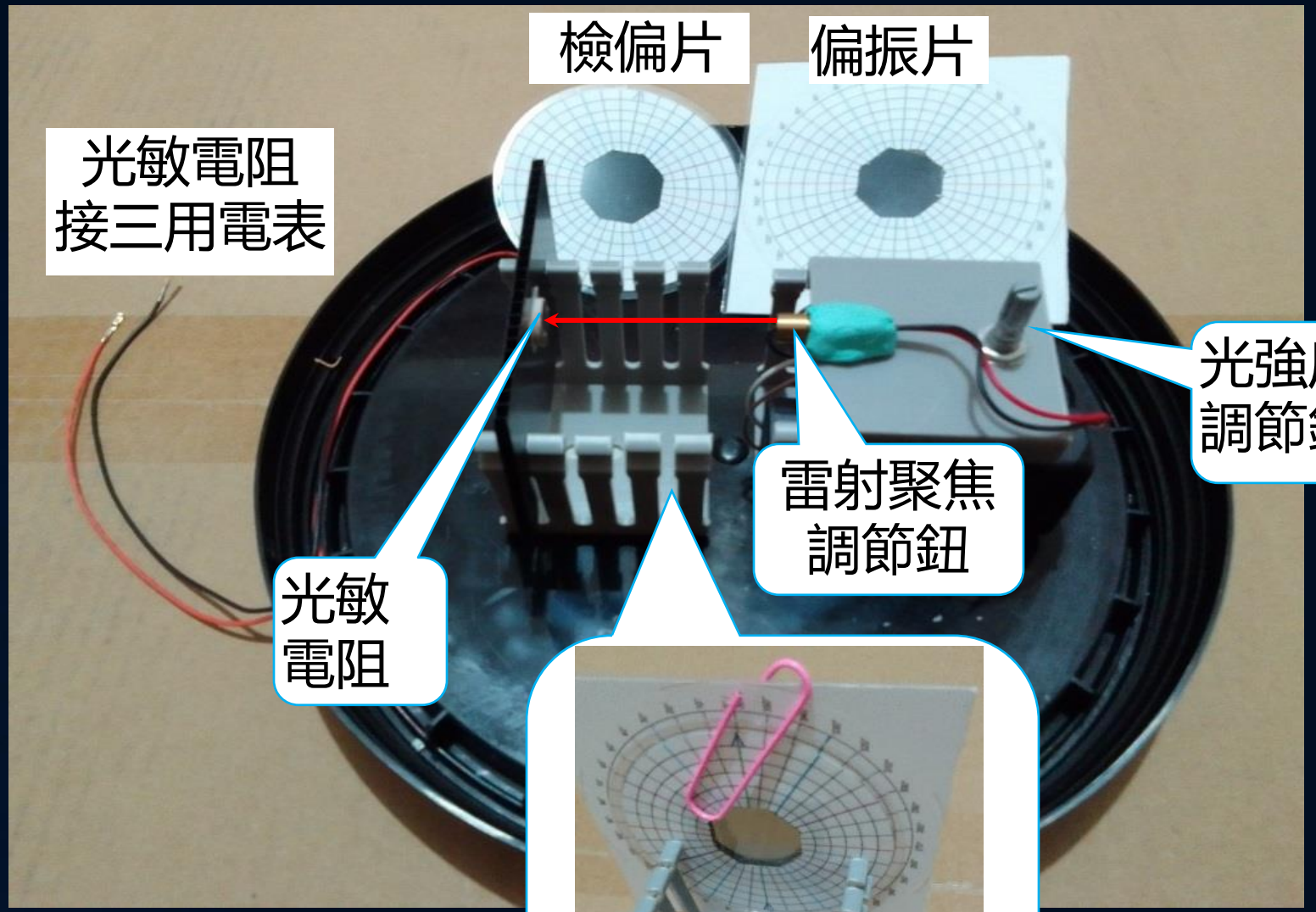
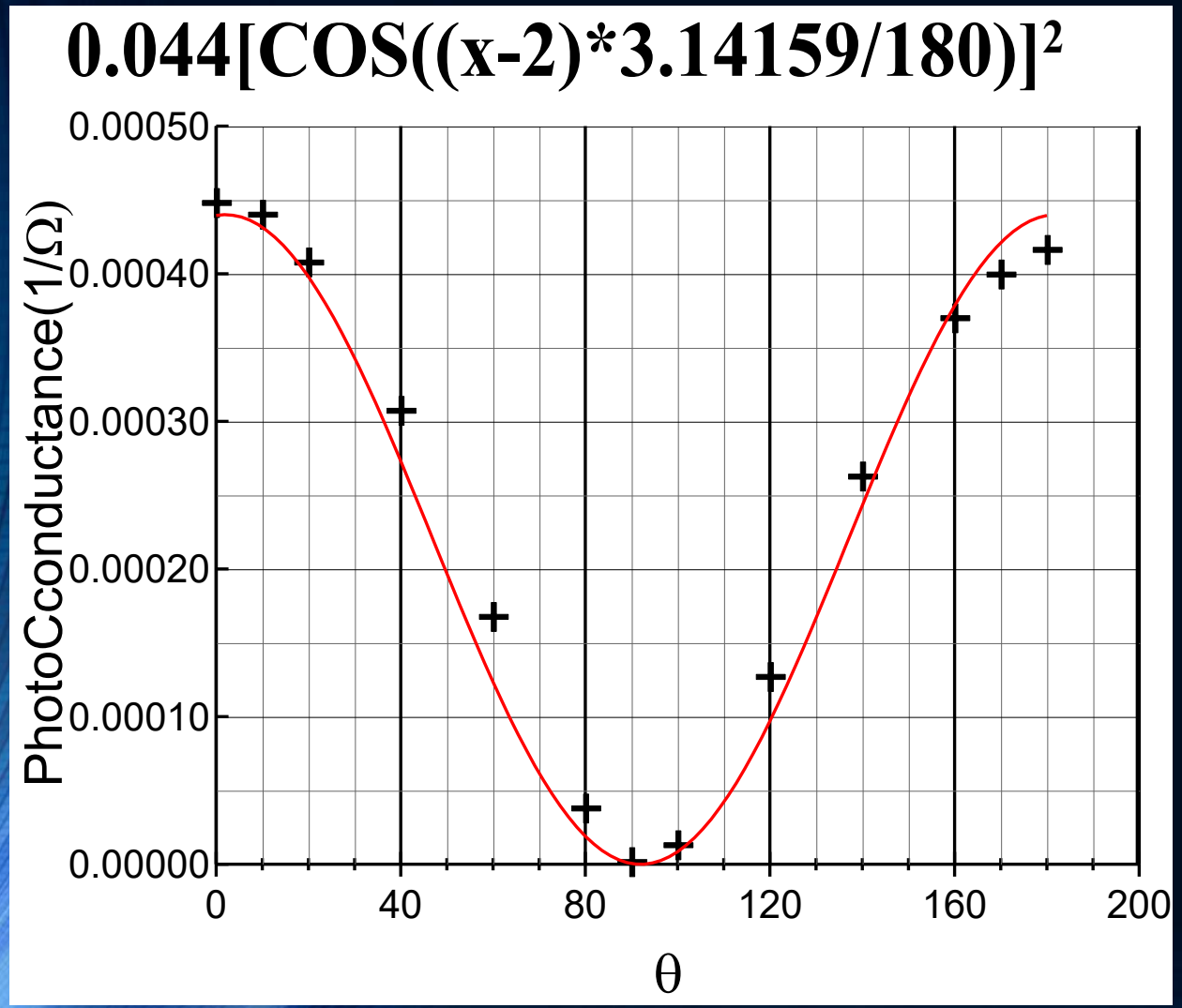
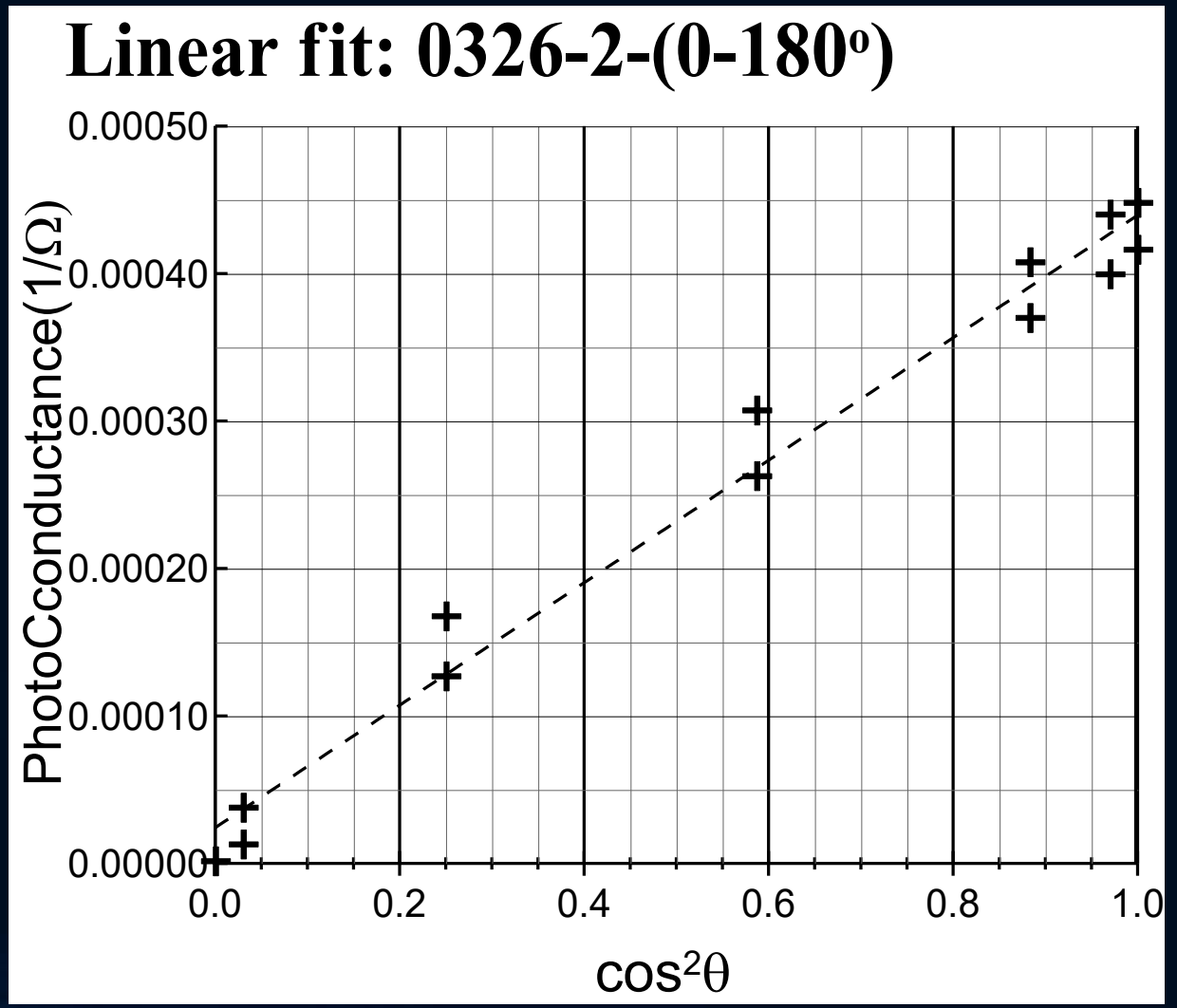


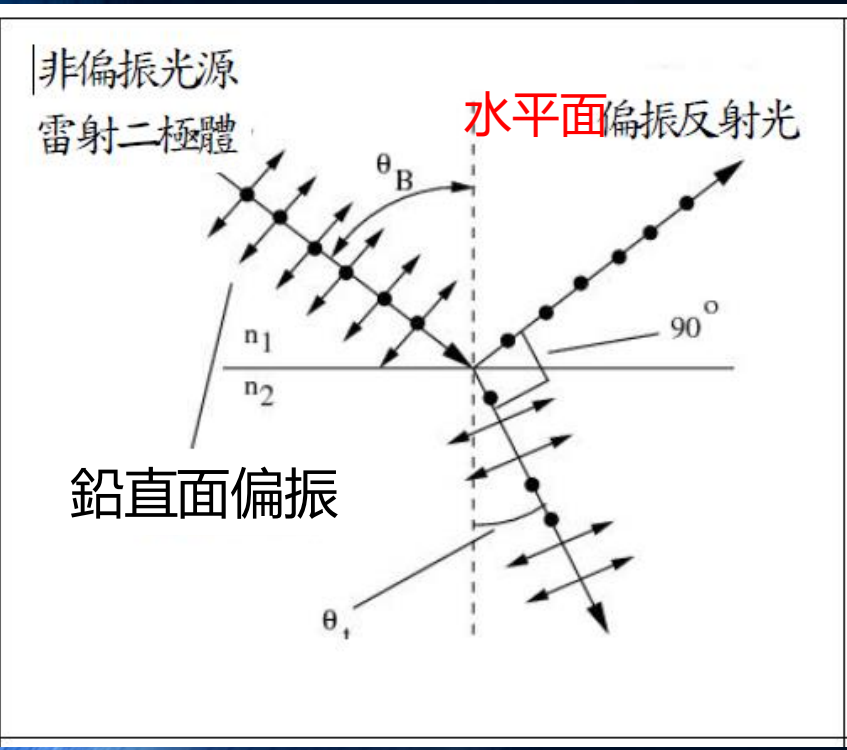
圖3光學元件與組合

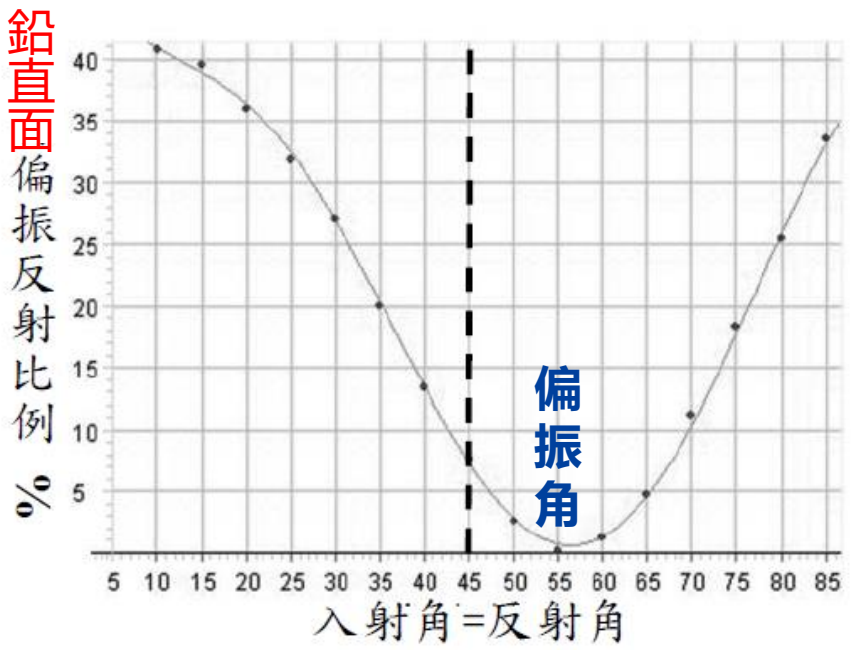
光偏振強度 VS. 檢偏片夾角: 數據與分析

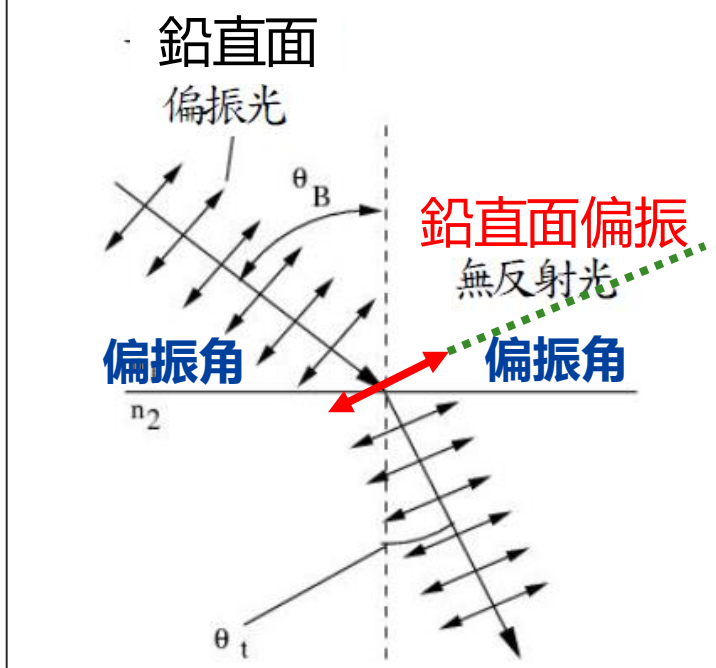




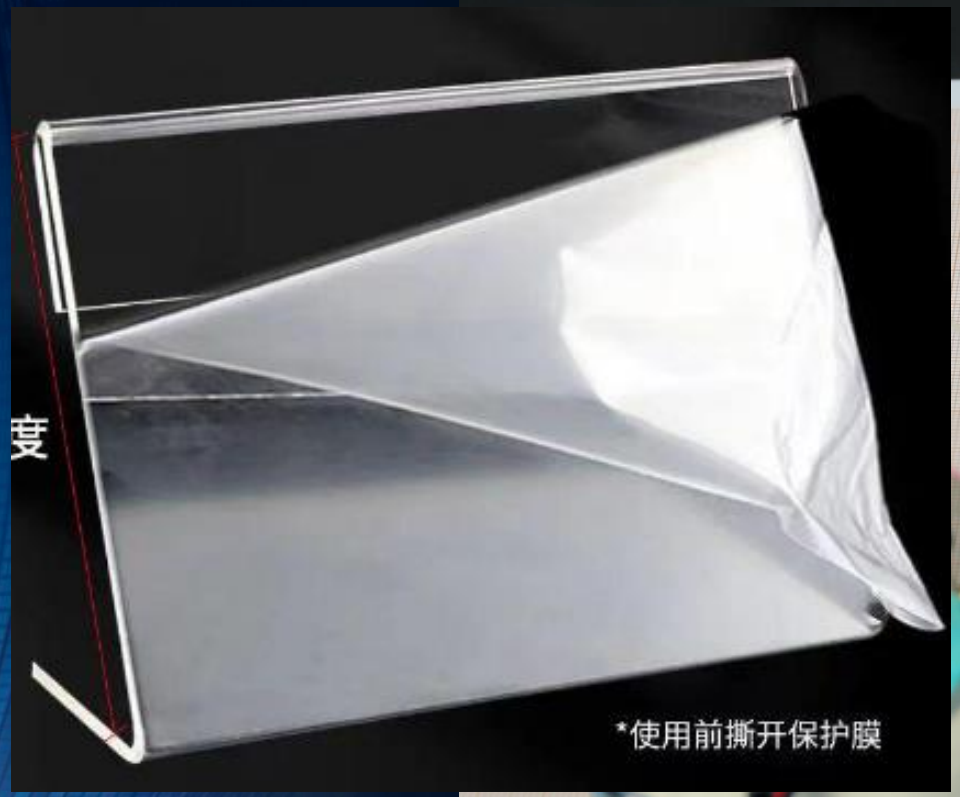
偏振角探究模組
原理:橫波不會沿**振動**方向**傳播**







偏振角探究模組: 裝置



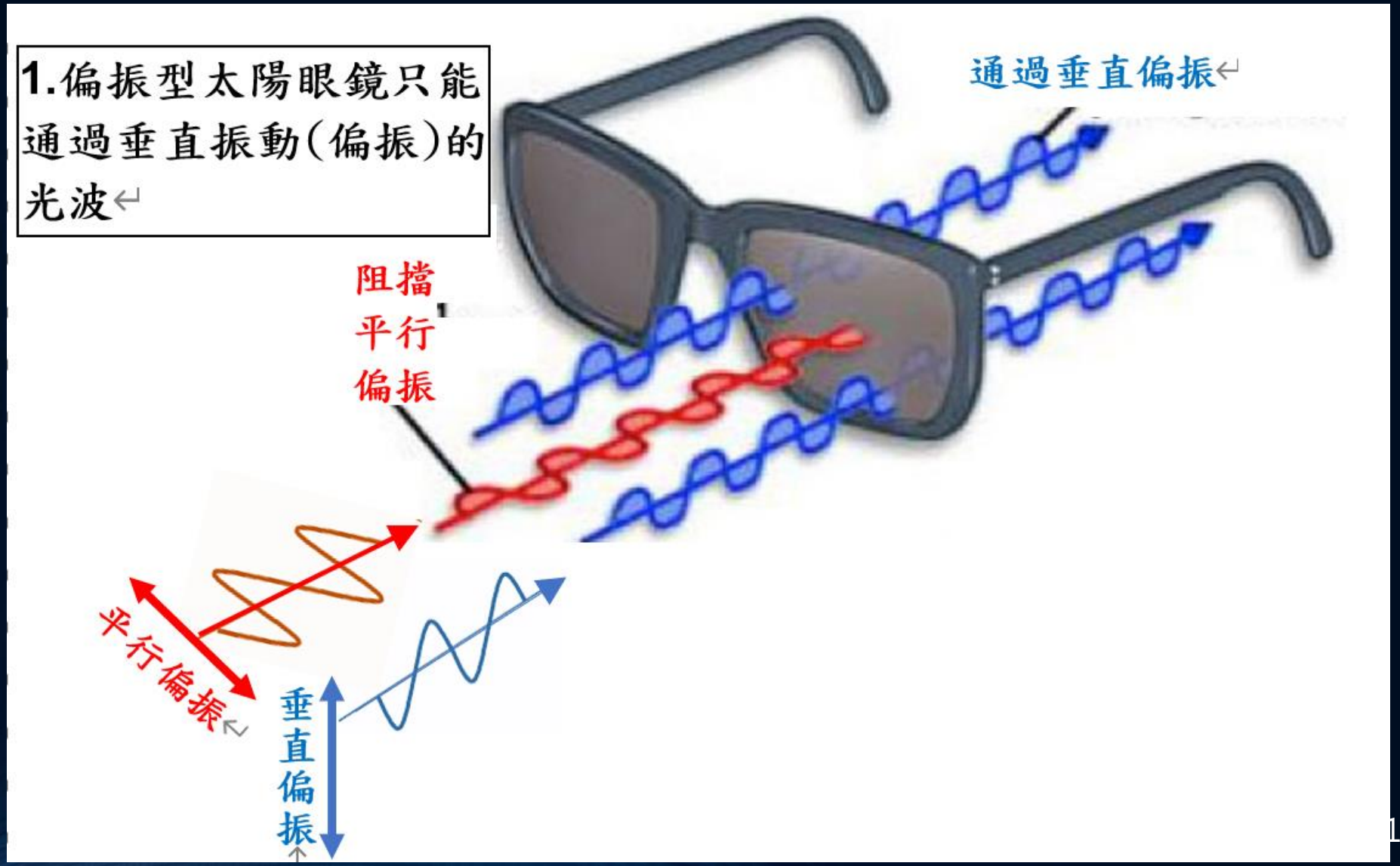
遮光罩(桶)

方格紙

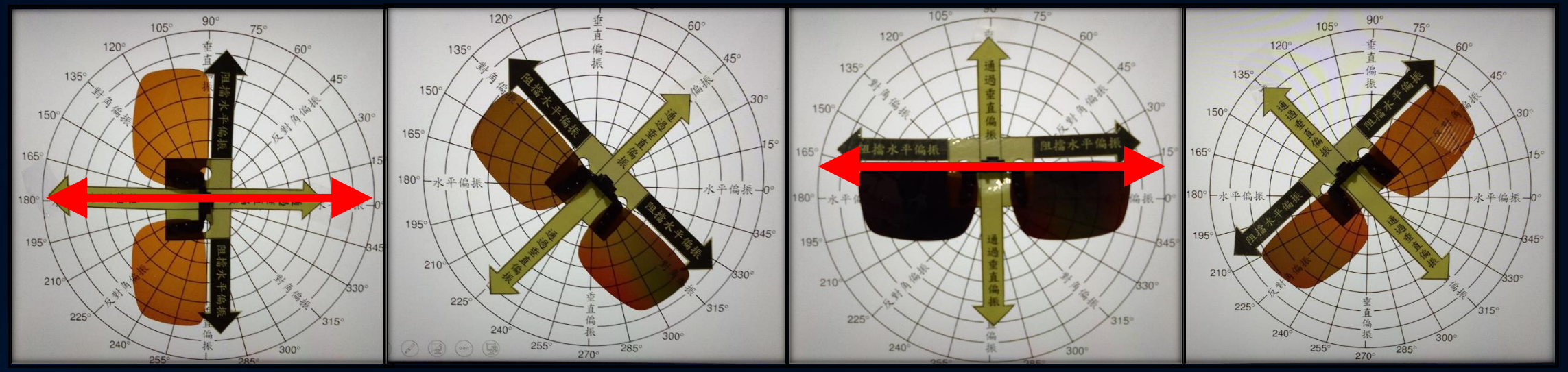
LCD 偏振探究模組:

偏振太陽眼鏡濾除水平偏振，通過垂直偏振

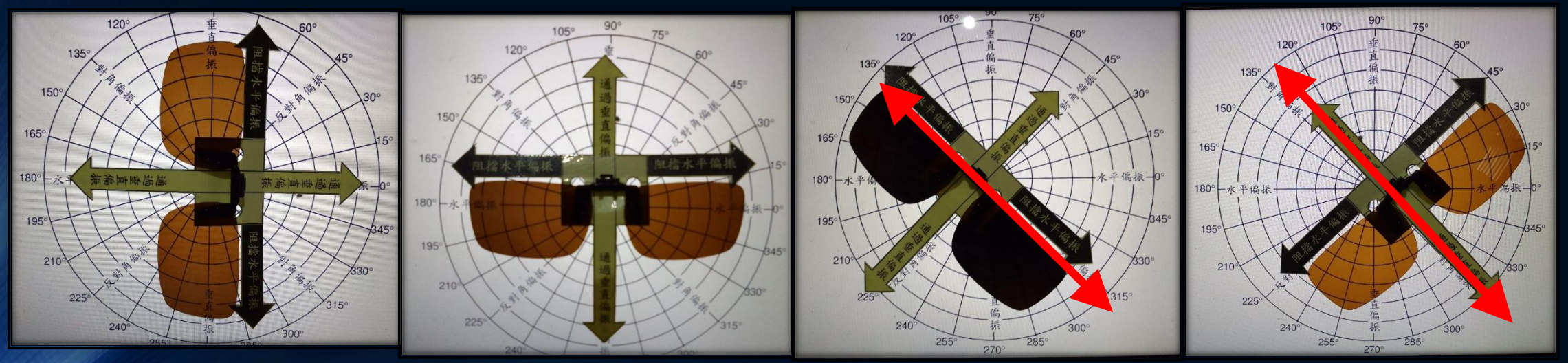
∵陽光反射多為水平偏振



水平偏振LCD



對角偏振LCD



全國科學博覽會

桃園高中
寒假營隊
手機測光