Explorando la ley de Planck con un smartphone

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Experimentos

"An experiment is a question which science poses to Nature and a measurement is the recording of Nature's answer."

Max Planck
Scientific Autobiography and Other Papers (1949)

Smartphone: Laboratorio portátil

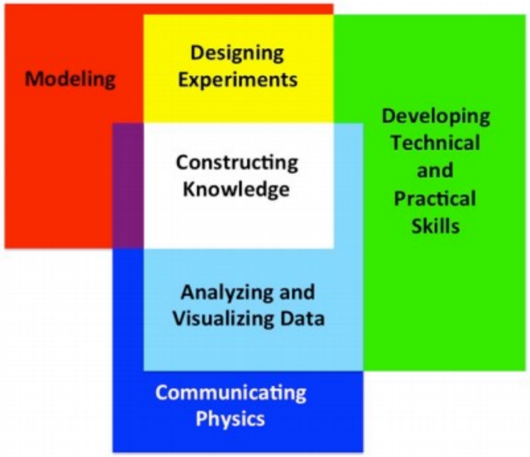
~~Herramienta para simplificar el laboratorio~~

Habilitar experimentación descentralizada

- Laboratorio en exteriores, viajes
- Laboratorio en casa
- **Requiere y permite el desarrollo de habilidades experimentales**

AAPT PHYSICS EDUCATION

AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum



Report prepared by a Subcommittee of the AAPT Committee on Laboratories
Endorsed by the AAPT Executive Board
November 10, 2014

AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum

Physics is a way of approaching problem solving, which requires direct observation and physical experimentation. Being successful in this endeavor requires one to synthesize and use a broad spectrum of knowledge and skills, including mathematical, computational, experimental, and practical skills; and to develop particular habits of mind. "Thinking like a physicist" and constructing knowledge of our physical universe pervade all of the recommended learning outcomes.

The undergraduate lab curriculum learning outcomes are based on the following focus areas.

- **Constructing knowledge** – collect, analyze, and interpret real data from personal observations of the physical world to develop a physical worldview.
- **Modeling** – develop abstract representations of real systems studied in the laboratory, understand their limitations and uncertainties, and make predictions using models.
- **Designing Experiments** – develop, engineer, and troubleshoot experiments to test models and hypotheses within specific constraints such as cost, time, safety, and available equipment.
- **Developing technical and practical laboratory skills** – become proficient using common test equipment in a range of standard laboratory measurements while being cognizant of device limitations.
- **Analyzing and visualizing data** – analyze and display data using statistical methods and critically interpret the validity and limitations of these data and their uncertainties.
- **Communicating Physics** – present results and ideas with reasoned arguments supported by experimental evidence and utilizing appropriate and authentic written and verbal forms.

Medir radiación térmica

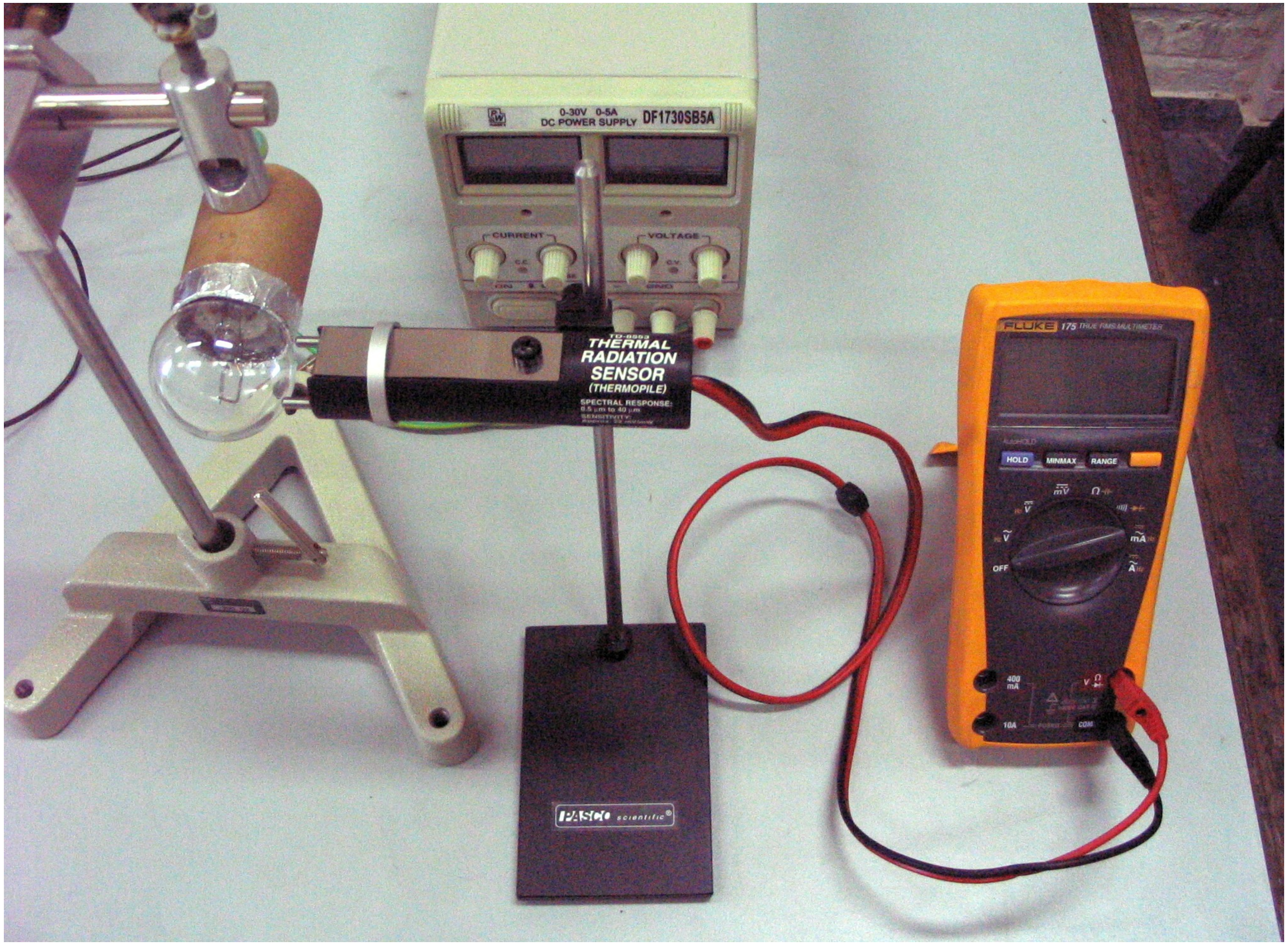
- Cámara
- Microfono
- Acelerómetro
- Giroscopio
- Magnetómetro
- ***Luz ambiente***
- Barómetro
- Orientación

DESAFÍO

Antecedente

Experimento clásico sobre Ley de Stefan-Boltzmann

$$L \propto T^4$$



Medida de Radiación Térmica

Ley de Planck.
Radiancia espectral:

$$R_T(\lambda)\,d\lambda = \frac{2\pi h c^2}{\lambda^5\left(e^{\frac{hc}{\lambda kT}}-1\right)}\,d\lambda$$

S-B según Planck:

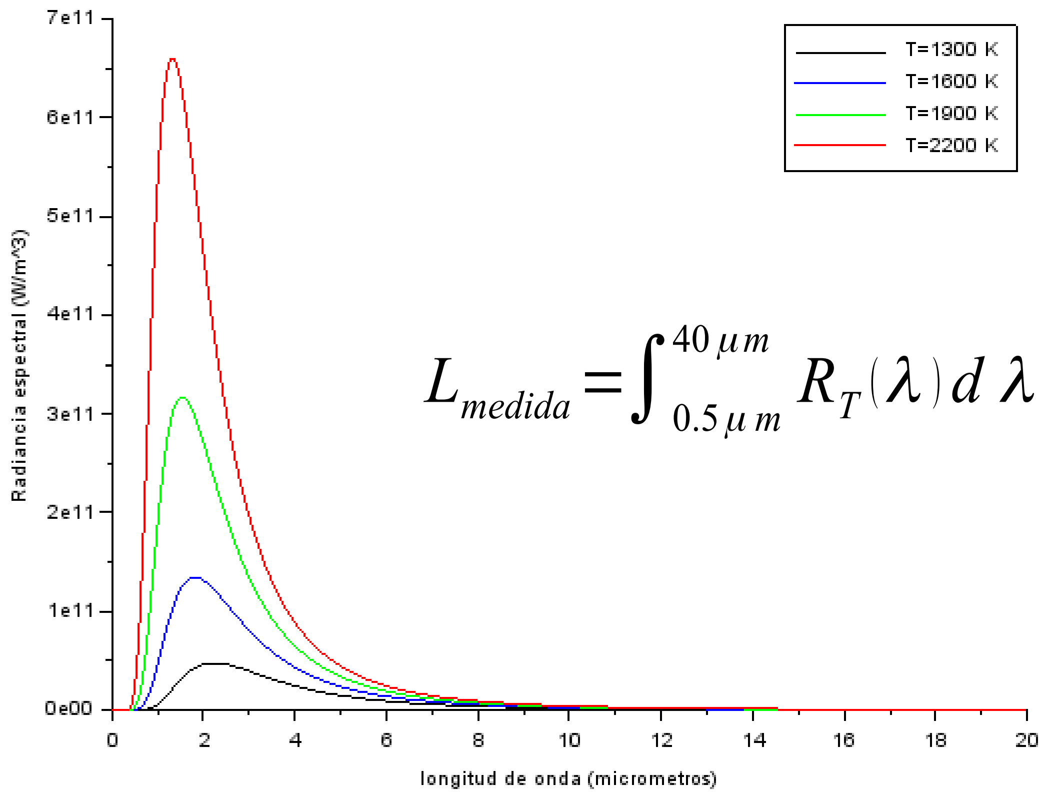
$$L=\int_0^{\infty} R_T(\lambda)\,d\lambda=\sigma T^4$$

L = Intensidad de RT (W/m²)

Medida de L con termopila
(serie de termocuplas Cu-Fe)

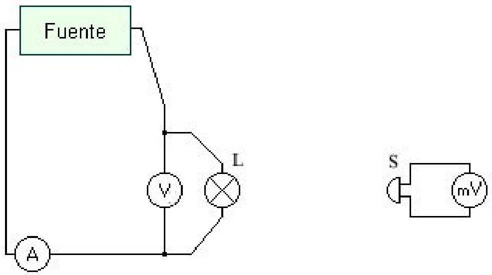
Efecto Seebeck

Voltaje proporcional a Radiación

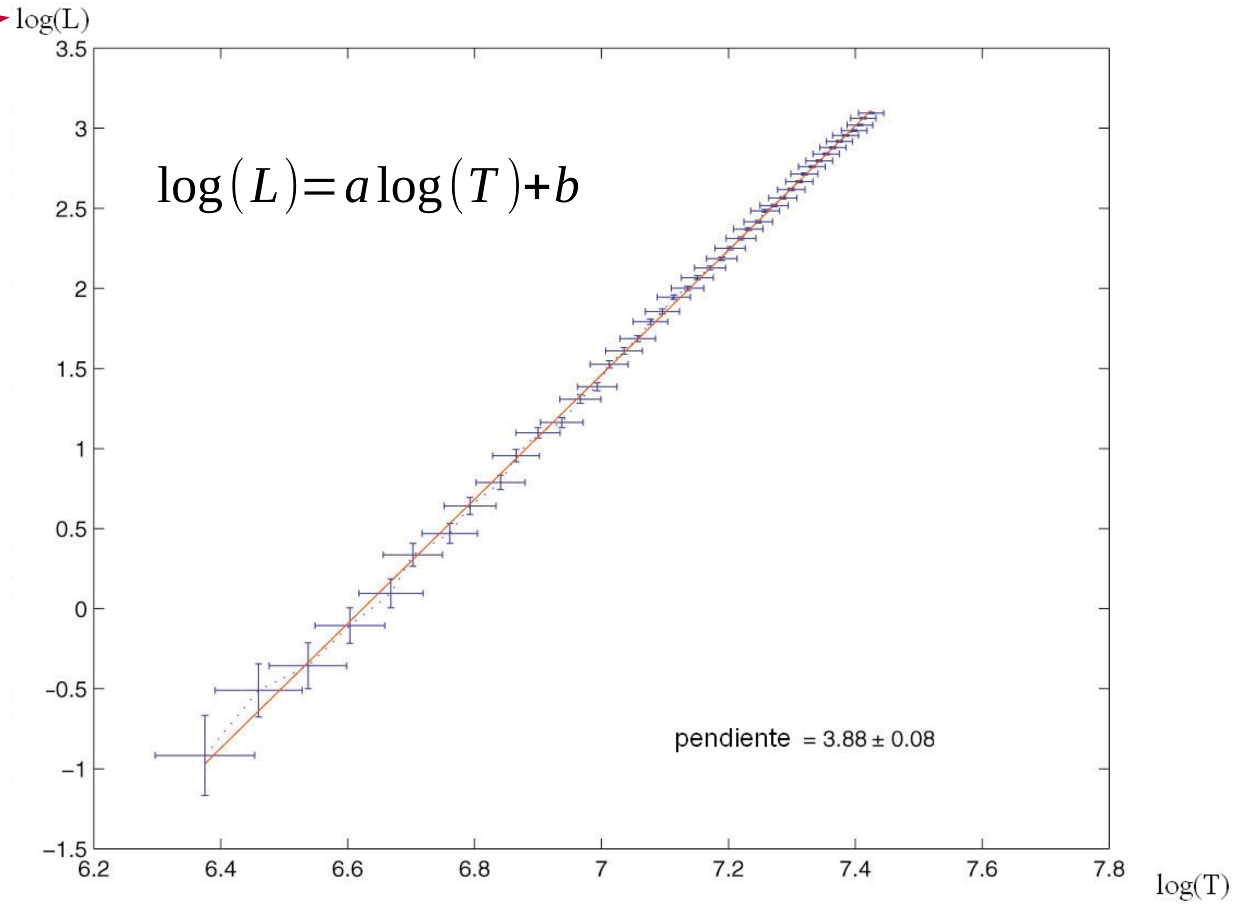


$$L_{medida}=\int_{0.5\,\mu m}^{40\,\mu m} R_T(\lambda)\,d\lambda \approx L$$

Ley de Stefan-Boltzmann



V (V)	I (A)	L (mV)
7.4	2.21	13.0
7.6	2.24	13.7
7.8	2.27	14.4
8.0	2.31	15.1
8.2	2.34	15.8
8.4	2.37	16.4
8.6	2.40	17.1
8.8	2.43	17.8
9.0	2.46	18.5
9.2	2.49	19.2
9.4	2.51	19.8
9.6	2.54	20.5
9.8	2.58	21.4
10.0	2.60	22.1



$R = V/I$

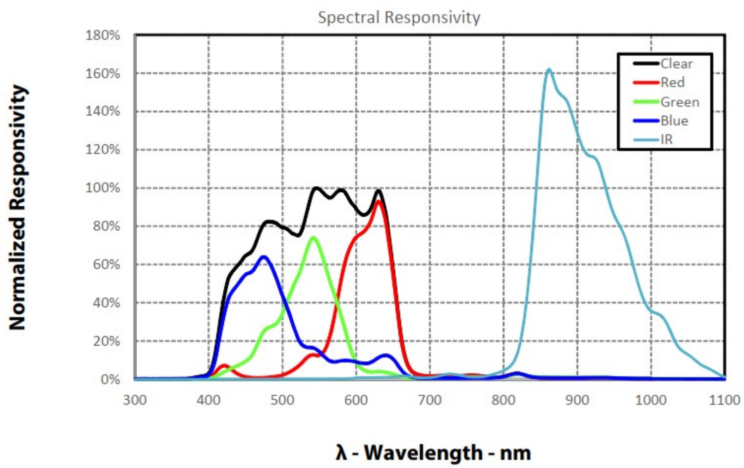
$R(T) = R_0 (1 + \alpha T + \beta T^2)$ → T

Medir radiación sin termocupla

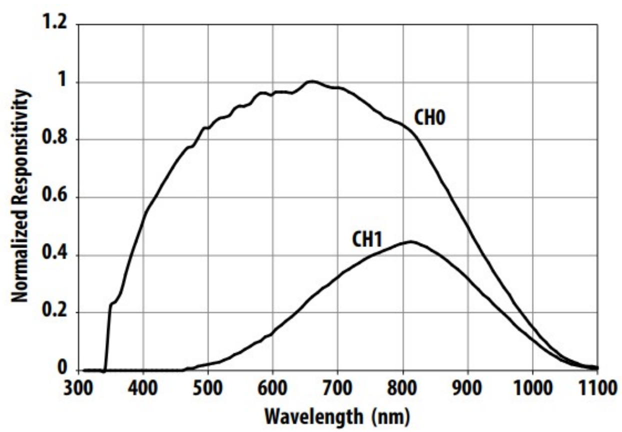
Sensor de luz ambiente del smartphone:

- Mide luminancia (función de transferencia similar a sensivilidad del ojo)
- Espectro mucho más angosto
- No es plano
- Diferentes modelos con diferentes sensores y diferentes respuestas

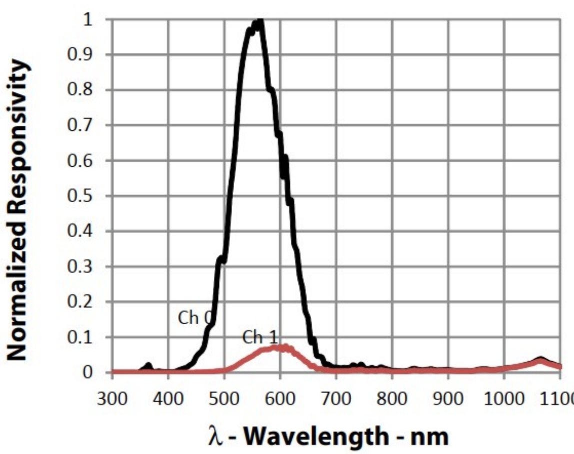
TDM4903
Samsung S7



APDS9930
Nexus 5



TSL2584
iPhone 6



¿Qué mide el sensor de luz?

Transferencia:

R_λ : Radiancia espectral incidente

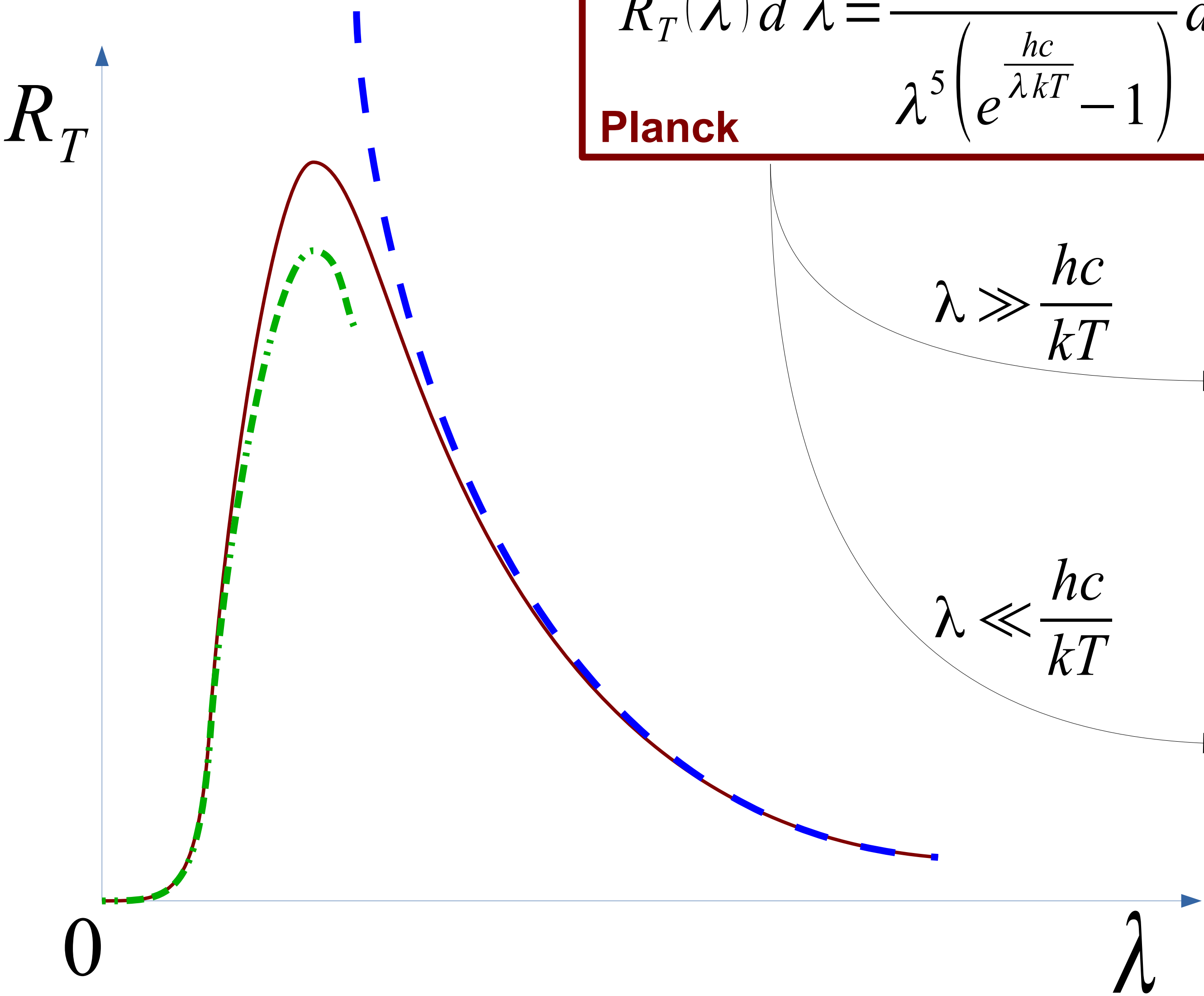
R_s : Respuesta espectral del sensor

$$L = \int_{-\infty}^{\infty} R_\lambda \cdot R_s \, d\lambda$$

Espectro angosto: No se puede medir radiación total (S-B).
(Pero no tan angosto)

¿Qué podemos medir de la Radiación Térmica?

Aproximaciones



Planck

$$R_T(\lambda)\,d\lambda = \frac{2\pi h c^2}{\lambda^5\left(e^{\frac{hc}{\lambda kT}}-1\right)}\,d\lambda$$

$$\lambda \gg \frac{hc}{kT}$$

Rayleigh-Jeans

$$R_T(\lambda)\,d\lambda \simeq \frac{2\pi c\,kT}{\lambda^4}\,d\lambda$$

$$\lambda \ll \frac{hc}{kT}$$

Wien

$$R_T(\lambda)\,d\lambda = \frac{2\pi h c^2}{\lambda^5 e^{\frac{hc}{\lambda kT}}}\,d\lambda$$

Aproximación de Wien

Lámpara incandescente

$$T \approx 2200\,K \quad \rightarrow \quad \frac{hc}{kT} \approx 6500\,\text{nm}$$

Lejos de la respuesta espectral del sensor

$$\lambda_{sensor} \ll \frac{hc}{kT}$$

Entonces es válida la aproximación de Wien:

$$R_T(\lambda) = 2\pi h c^2 \lambda^{-5} e^{-\frac{hc}{\lambda kT}}$$

Medida aproximada con el sensor

$$L \approx \int_{\lambda_L}^{\lambda_U} 2\pi h c^2 \lambda^{-5} e^{-\frac{hc}{\lambda kT}} d\lambda$$

Límites, inferior y superior de respuesta del sensor de luz

Teorema del valor medio

$$L \approx 2\pi h c^2 \lambda_0^{-5} e^{-\frac{hc}{\lambda_0 kT}} \Delta\lambda$$

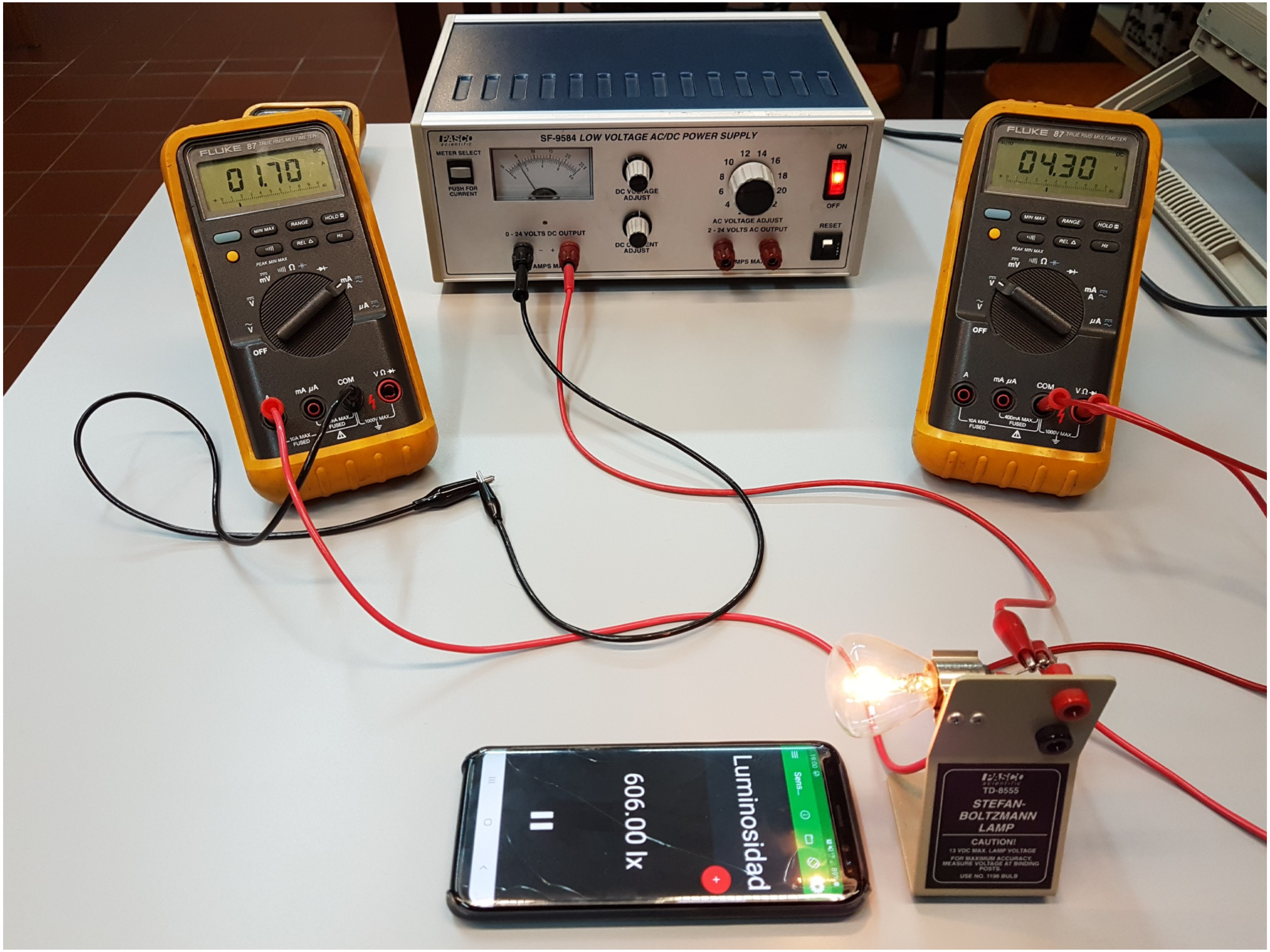
Longitud de onda “media” de la respuesta espectral del sensor

Intensidad medida por el sensor de luz en función de la temperatura del filamento

$$L \approx A e^{\left(\frac{B}{T}\right)}$$

$$B = -\frac{hc}{\lambda_0 k}$$

Experimento



Medidas

Para diferentes temperaturas del filamento, se mide:

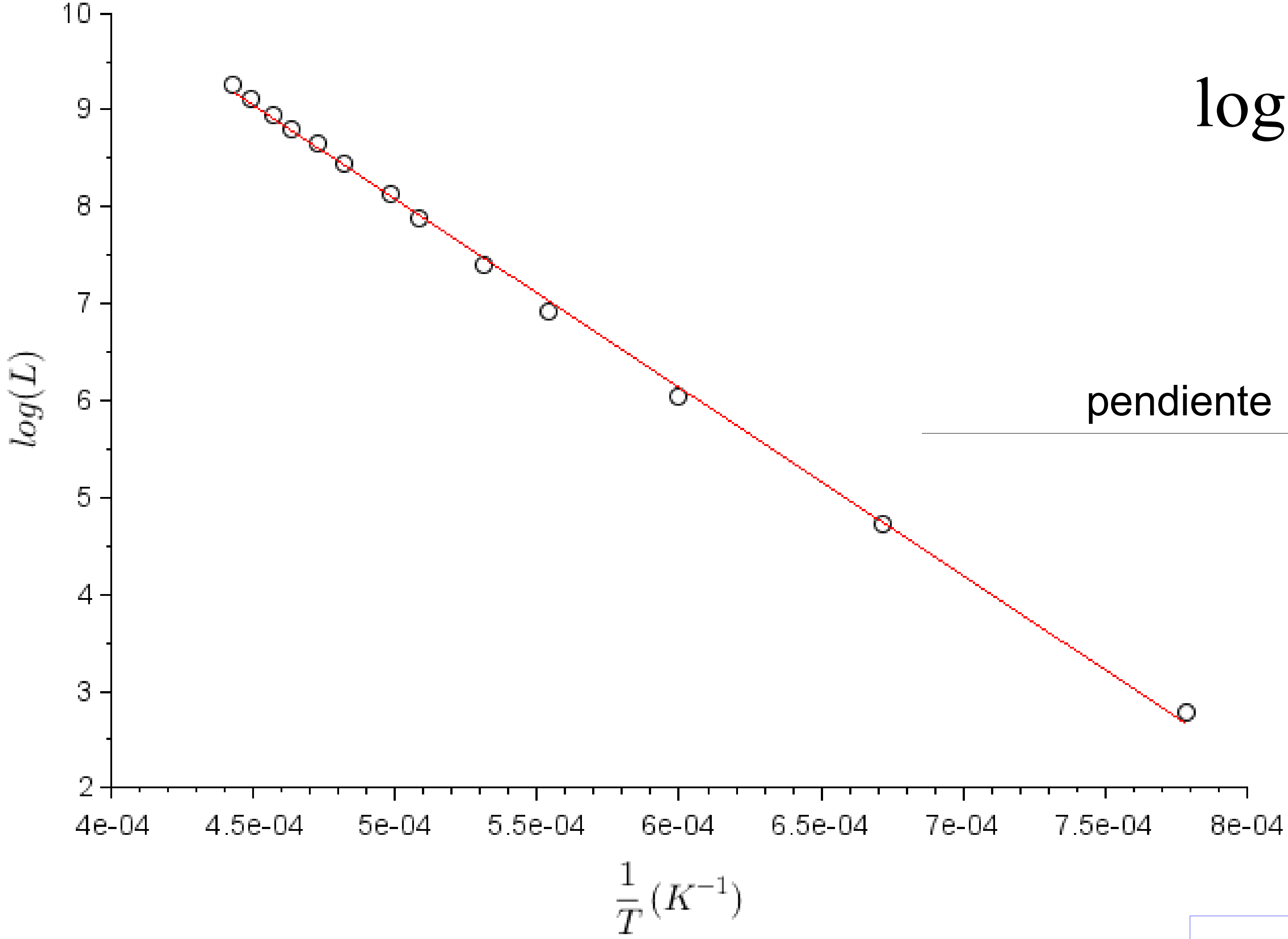
- *L* = Iluminancia (smartphone)
- *V* = Diferencia de potencial en el filamento (voltímetro)
- *I* = Intensidad de corriente (amperímetro)

De *V* e *I* se obtiene la temperatura del filamento.

Finalmente se construye la gráfica log(*L*) vs. 1/*T*

$$\log(L) \approx \log(A) + \frac{B}{T}$$

Resultados



$$\log(L) \approx \log(A) + \frac{B}{T}$$

pendiente →

$$B = -\frac{hc}{\lambda_0 k}$$

$$h = 6.7 \times 10^{-34} J \cdot s$$

Gracias