Problem №13 “Light bulb”

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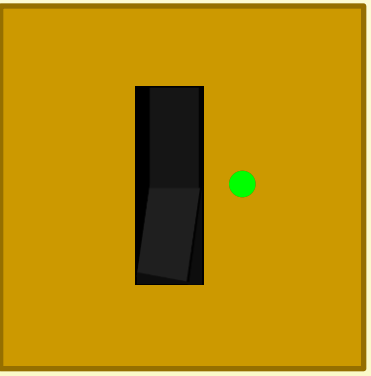
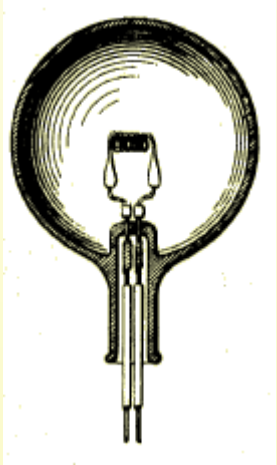


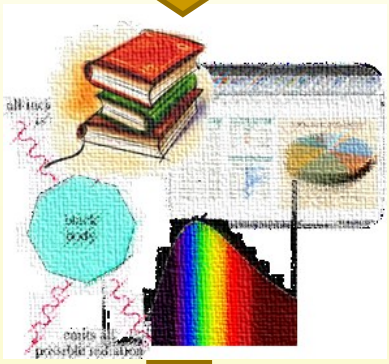


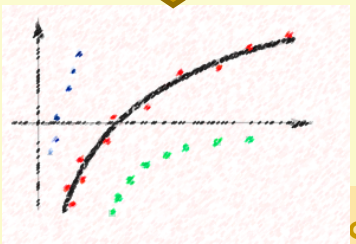
The statement of problem

- What is the ratio between the thermal energy and light energy emitted from a small electric bulb depending on the voltage applied to a bulb?

Key objectives of my research

- Experimental set up
- Observation
- Measurement and procession
- Investigation and proposition
- Qualitative explanation and estimation
- Investigation of radiant emission theory
- Theoretical plot
- Comparison and conclusion



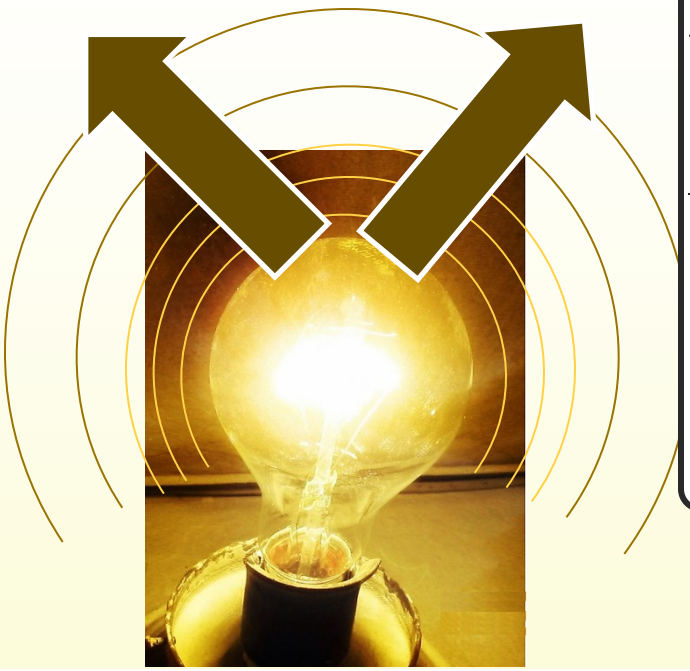


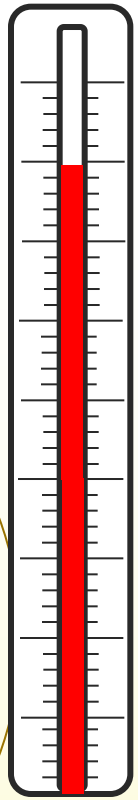
Hypothesis

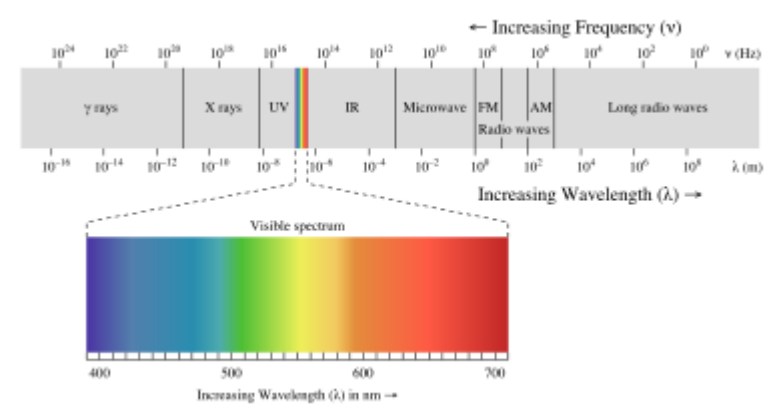
- We expect the increment of required ratio while the voltage rises.

Initial propositions

- The bulb is a radiator.
- The wavelength range of the light is from 380 to 780 nm.
- The “heat” portion has a wavelength of continuous spectrum.





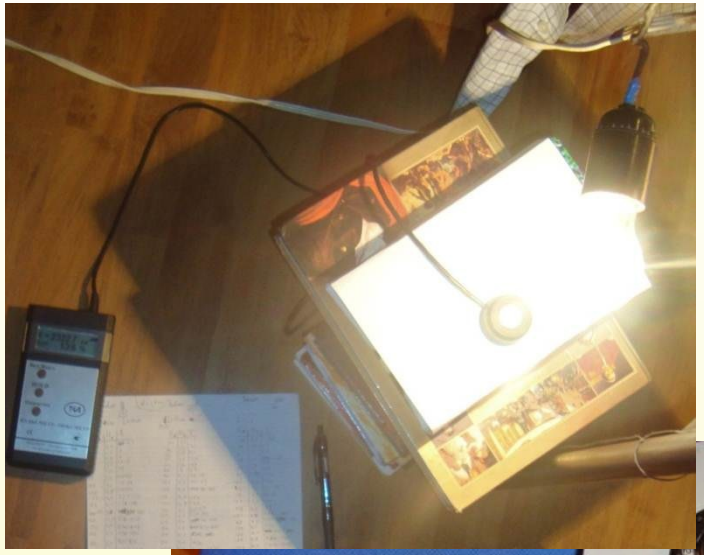


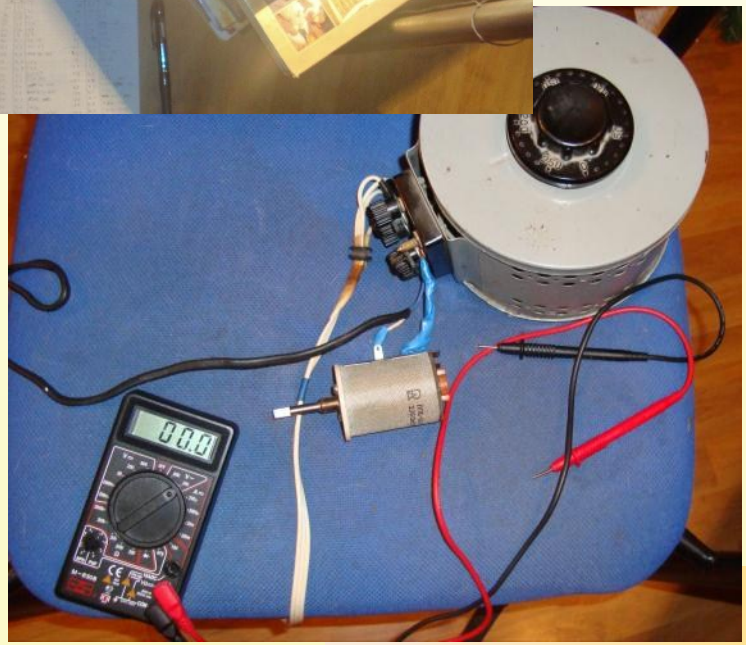
Thus, the ratio required is :

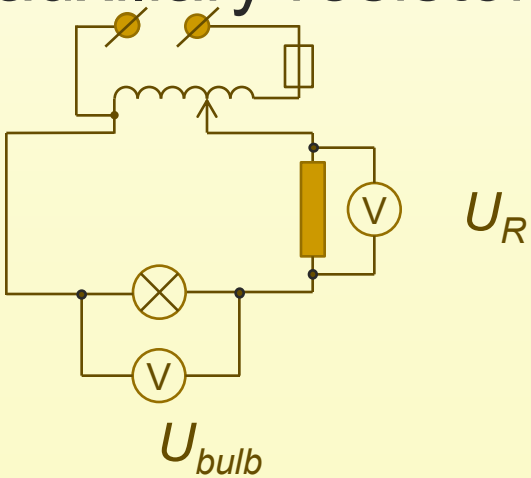
$$\frac{P_{light}}{P_{therm}} = \frac{P_{light}}{P_{\Sigma radiant}} = \frac{P_{light}}{I \cdot U}$$

The elements of my set up

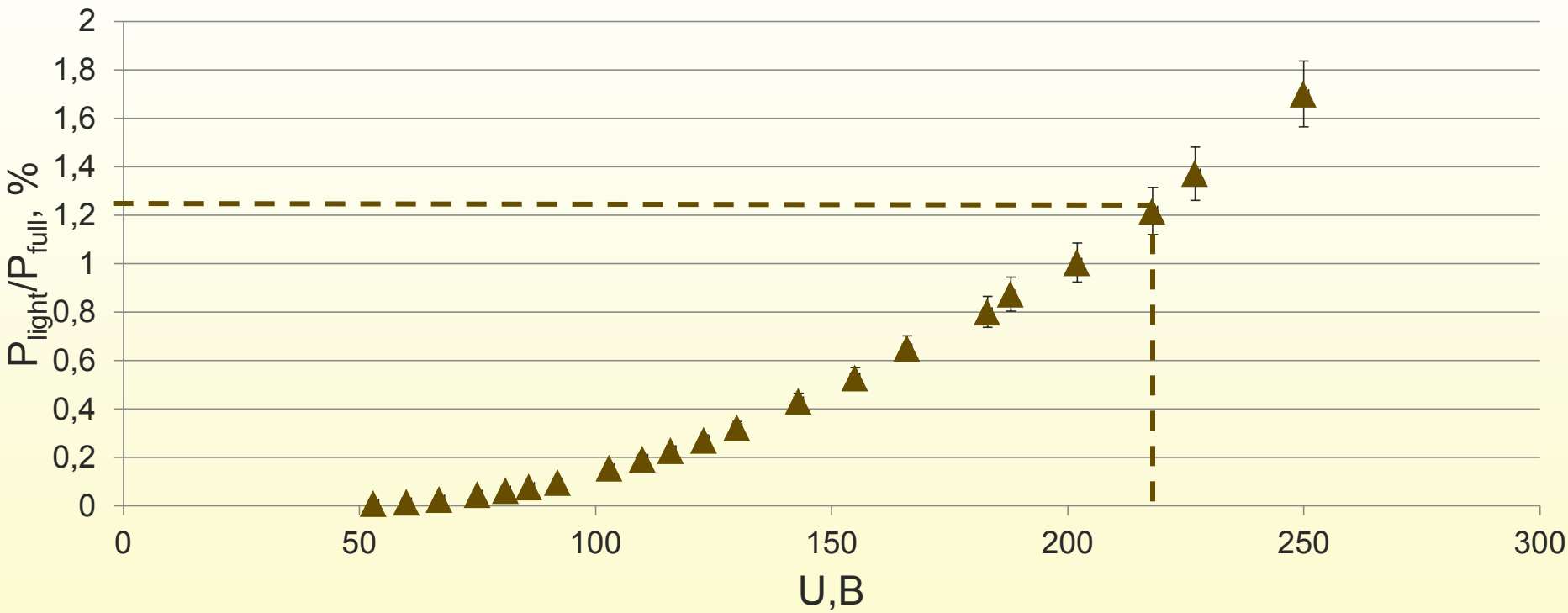
- An autotransformer with the AC output 0..250V
- A light bulb 220V 60W
- A luxmeter “TKA-PKM”
- A multimeter
- An auxiliary resistor





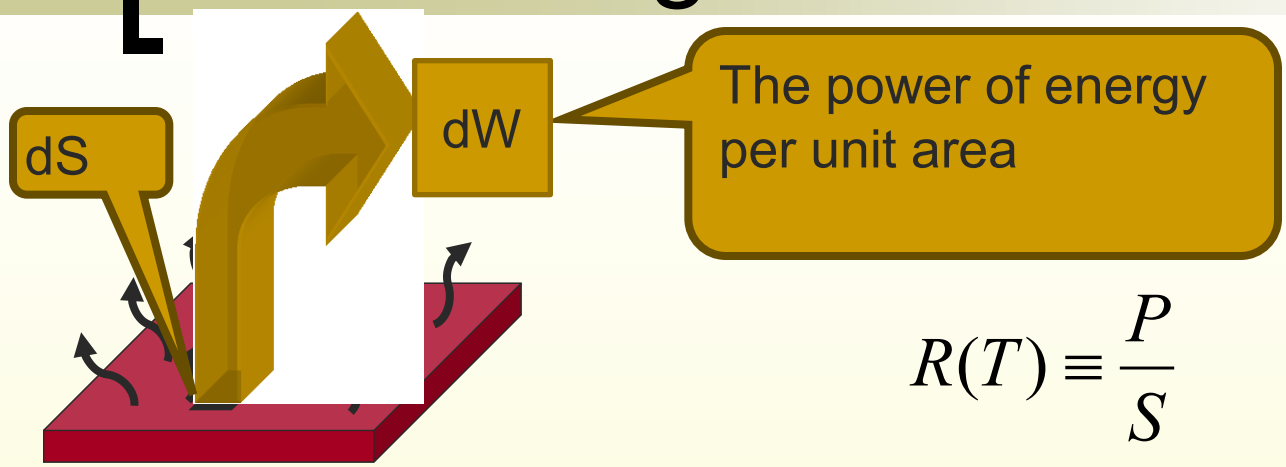


The experimental result



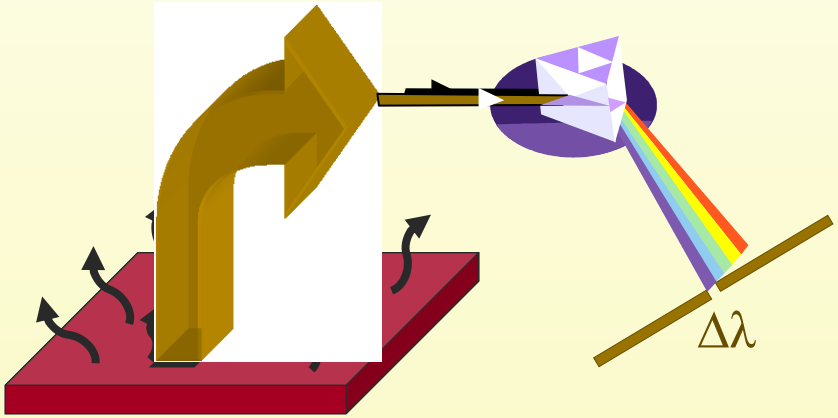
- For the rated voltage 220V required ratio is about 1.2%

Electromagnetic radiation



$$R(T) \equiv \frac{P}{S}$$

$R(T)$ – radiant emittance



$$r(\lambda, T) = \frac{P(\lambda, \lambda + \Delta\lambda)}{S\,\Delta\lambda}$$

$r(\lambda, T)$ – spectral density of radiant emittance

Blackbody model

- A black body doesn't reflect a light. However it's the best thermal emitter, which means its coefficient of thermal radiation is ε=1

Stefan – Boltzmann's law for blackbody :

$$R = \sigma T^4 \qquad \text{When a gray body is considered } (\varepsilon < 1)$$

$$R = \sigma T^4 \varepsilon$$

$$\sigma = 5.67 \cdot 10^{-8} \frac{W}{m^2 K^4}$$

R – radiant emittance

T – temperature

Blackbody radiation

r(λ,T),
W/(m²·m)

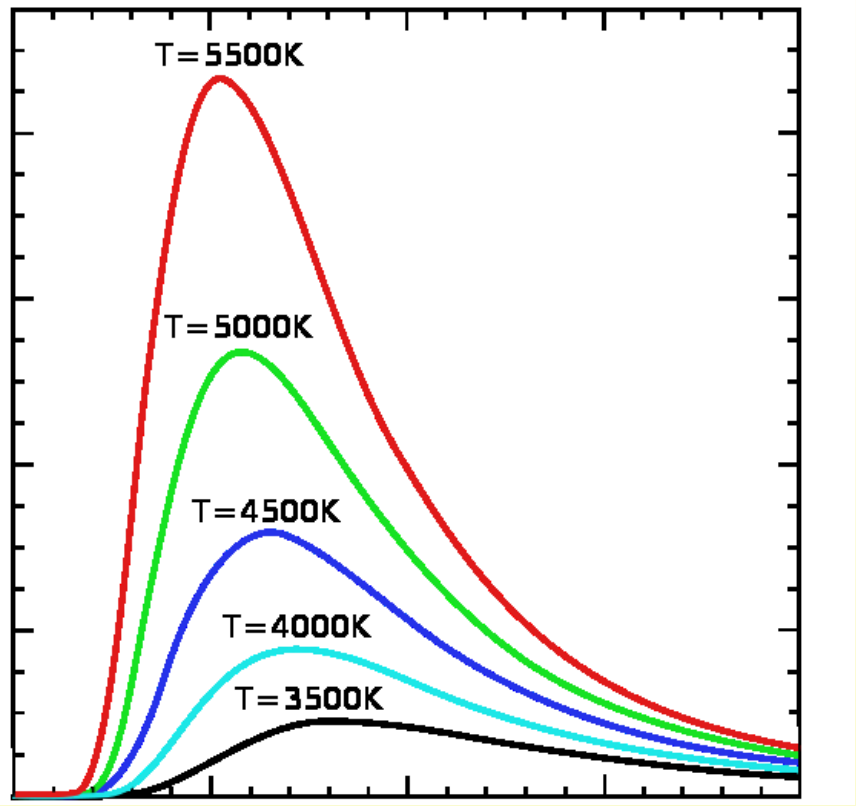
The Plank's law :

$$r(\lambda,T)=\frac{2\pi hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda\cdot kT}}-1}$$

$$c=3\cdot 10^8\,\frac{m}{s}$$

$$\mathrm{h-Plank's\ constant,\ h}=6{,}626\cdot 10^{-34}\,\mathrm{J\cdot s}$$

$$k=1{,}38\cdot 10^{-23}\,\frac{J}{K}$$



λ, m

Radiant emittance of blackbody

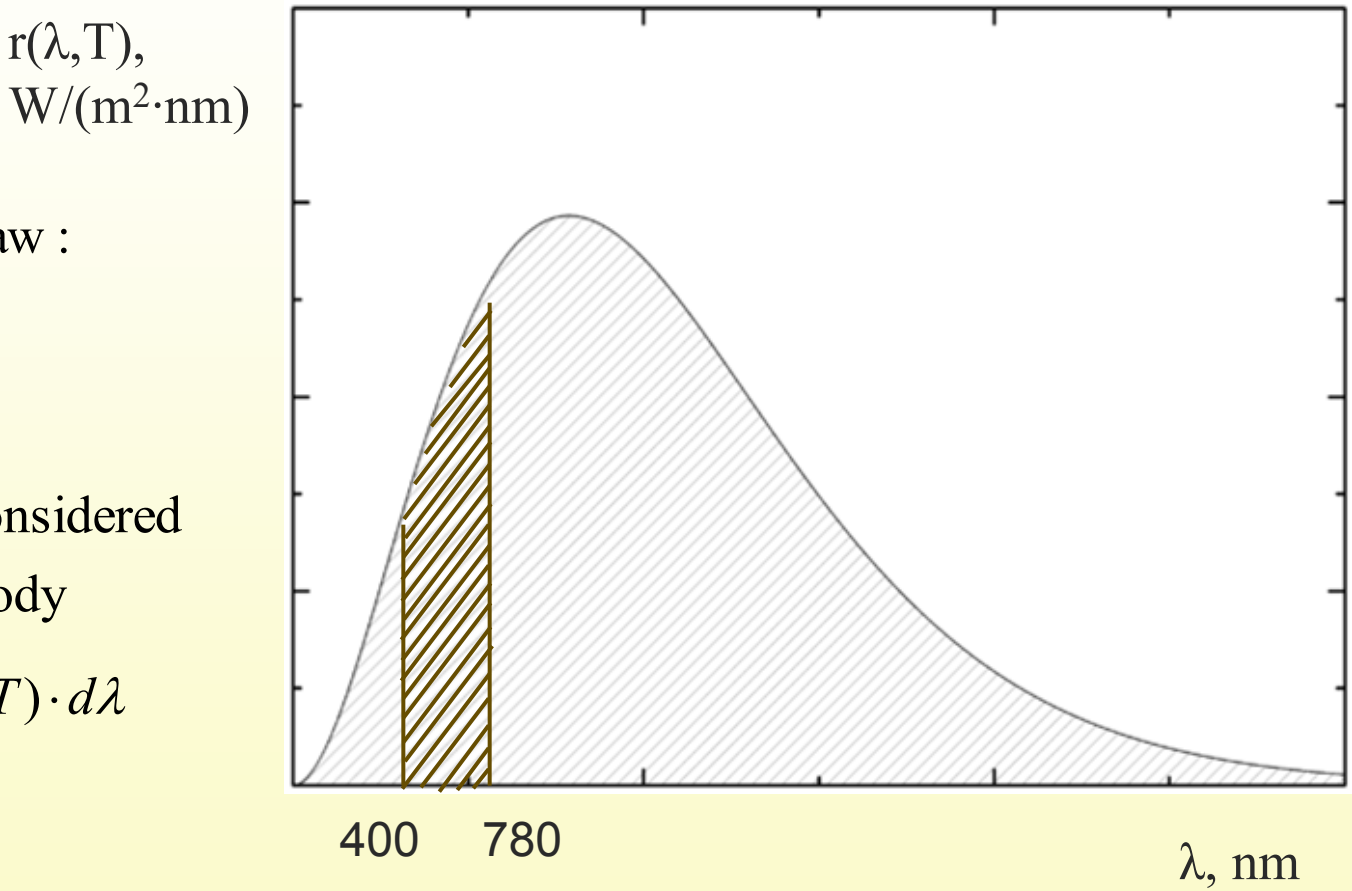
The derivation of

Stefan – Boltzmann's law :

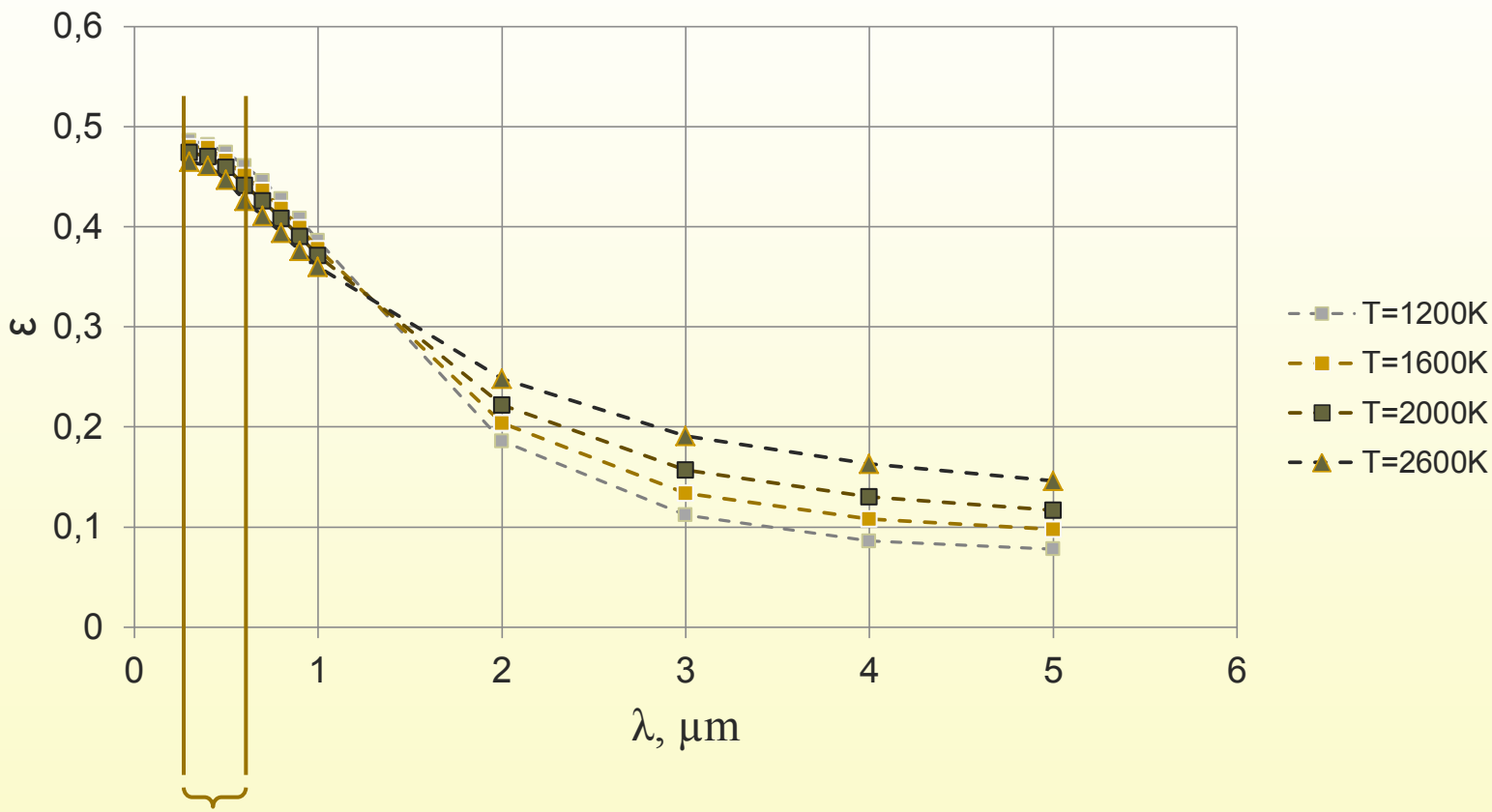
$$R_T = \int_0^{\infty} r(\lambda, T) \cdot d\lambda$$

Radiant emittance considered as visible light :

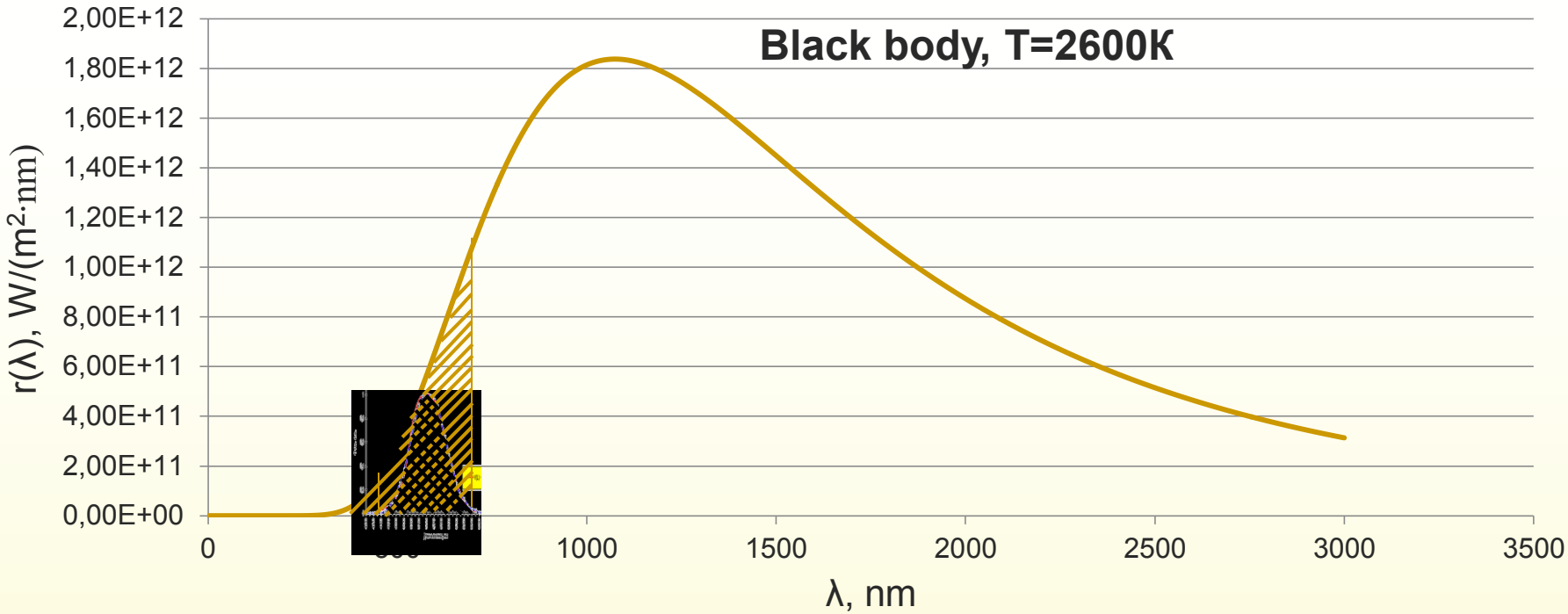
$$R = \int_{380}^{780} r(\lambda, T) \cdot d\lambda$$



Relation between emissivity and temperature and wavelength ε(λ), ε(T)

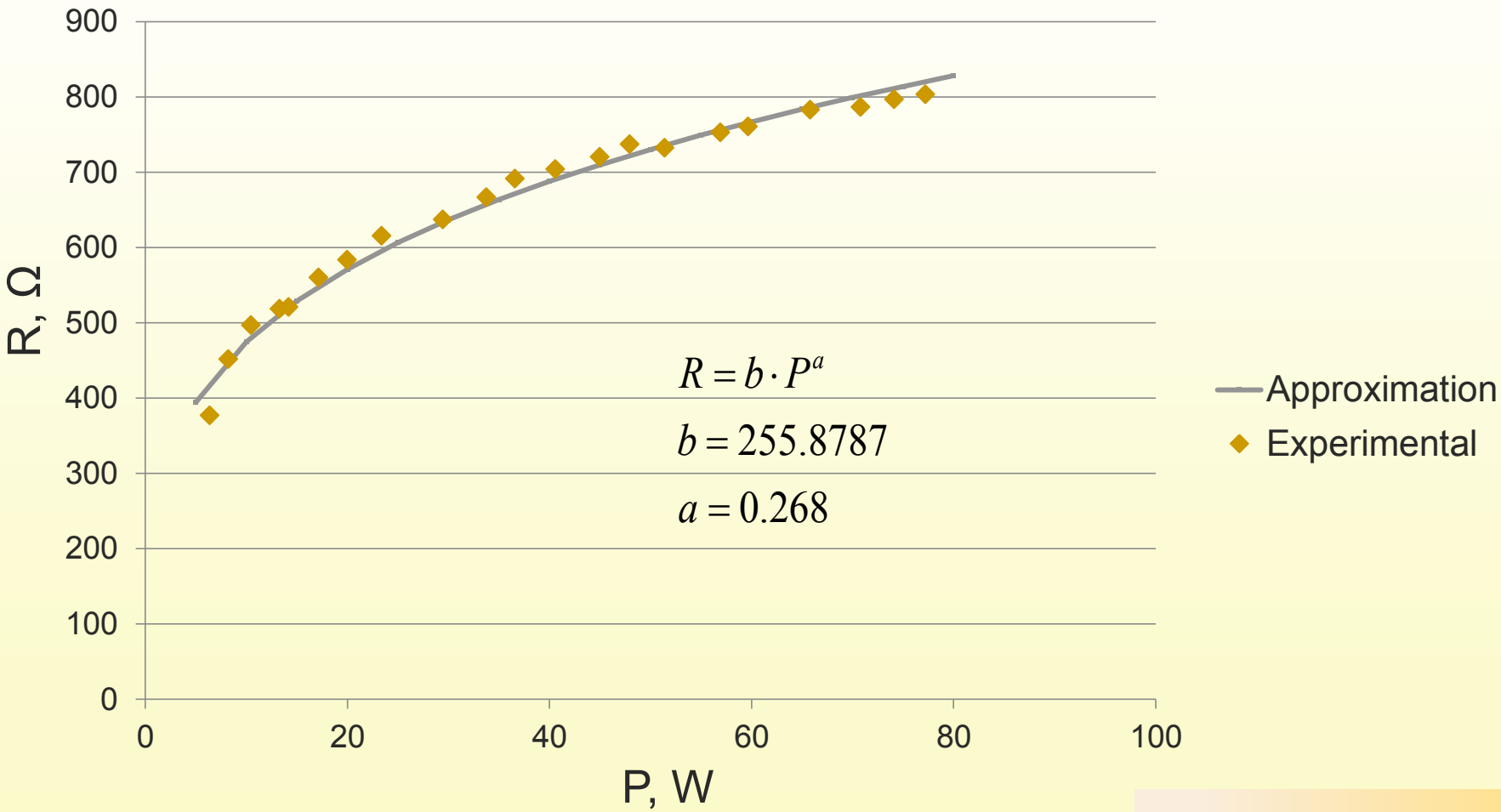


$\langle \varepsilon_{visual} \rangle = 0.45$

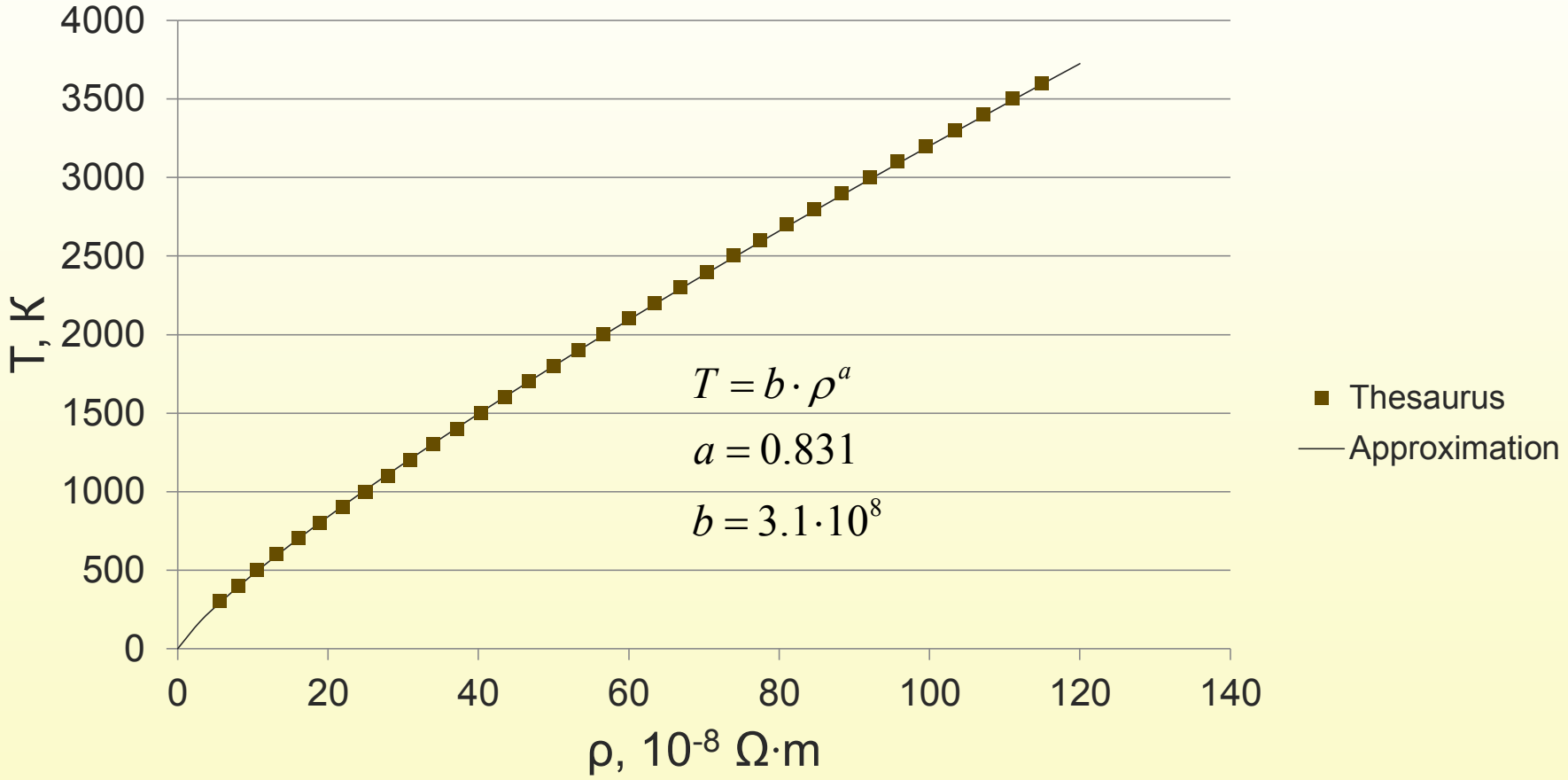


- Human eye perceives a small part of the whole continuous spectrum

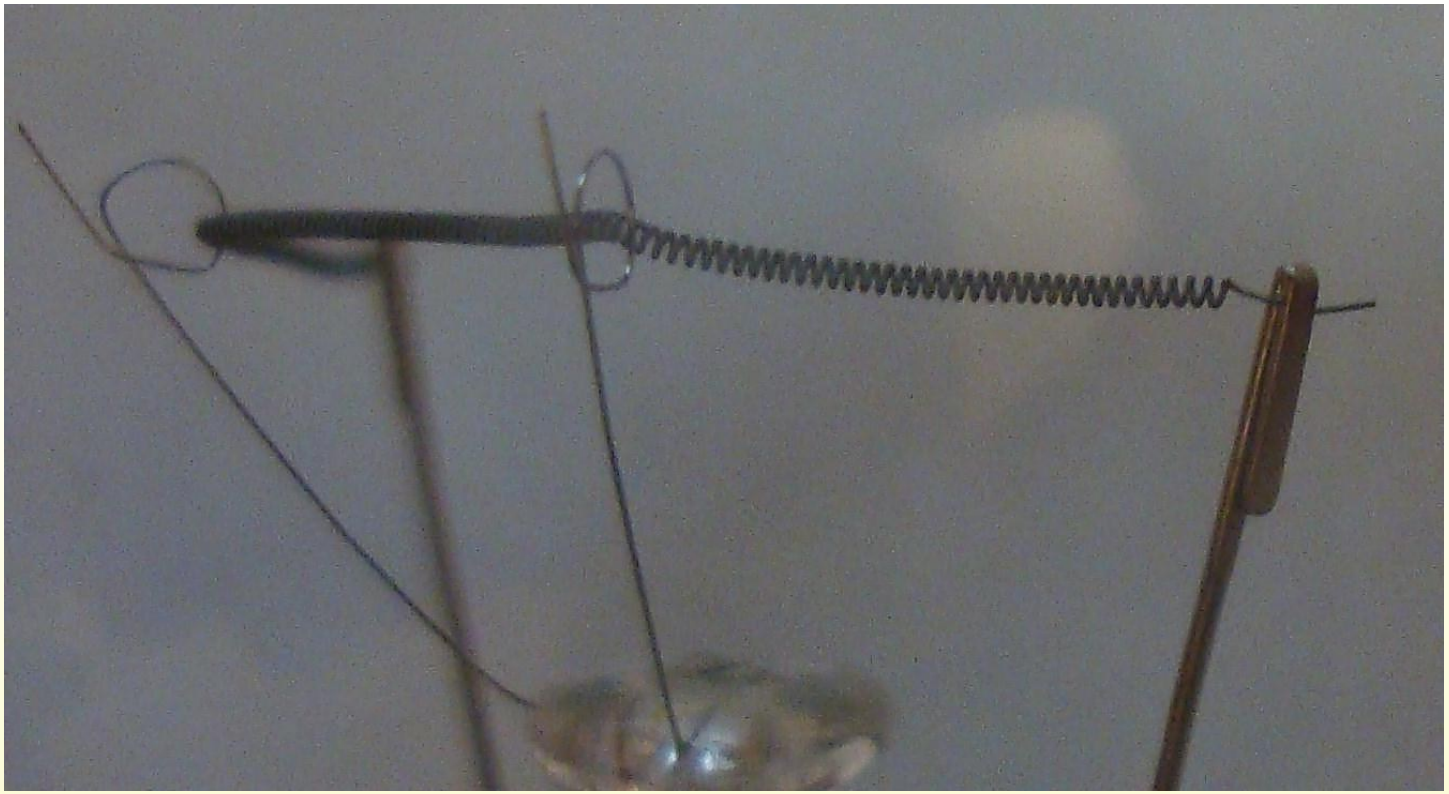
The relation of coil resistance to the full power.



The relation of temperature to resistivity



$d_{wire} \approx 1.5 \cdot 10^{-5}$ m



$d_{spin} = 0.5\ mm$

there're 162 spins in the coil

The surface area is

$$S_{surf} = 162 \cdot \pi^2 d_{turn} d_{coil} = 1{,}9 \cdot 10^{-10} m^2$$

The algorithm of quantitative estimation

1

$$R = b \cdot P^a$$

R – resistance

$b = 255.8787$

$a = 0.268$`

2

$$\rho = \frac{RS_{cross-section}}{l}$$

$S_{c-s} = 1.9 \cdot 10^{-10} m^2$

$l = 0.25m$

3

$$T = b \cdot \rho^a$$

$a = 0.831$

$b = 3.1 \cdot 10^8$

4

$$R_{вид} = \int_{380}^{780} r(\lambda, T) \cdot d\lambda$$

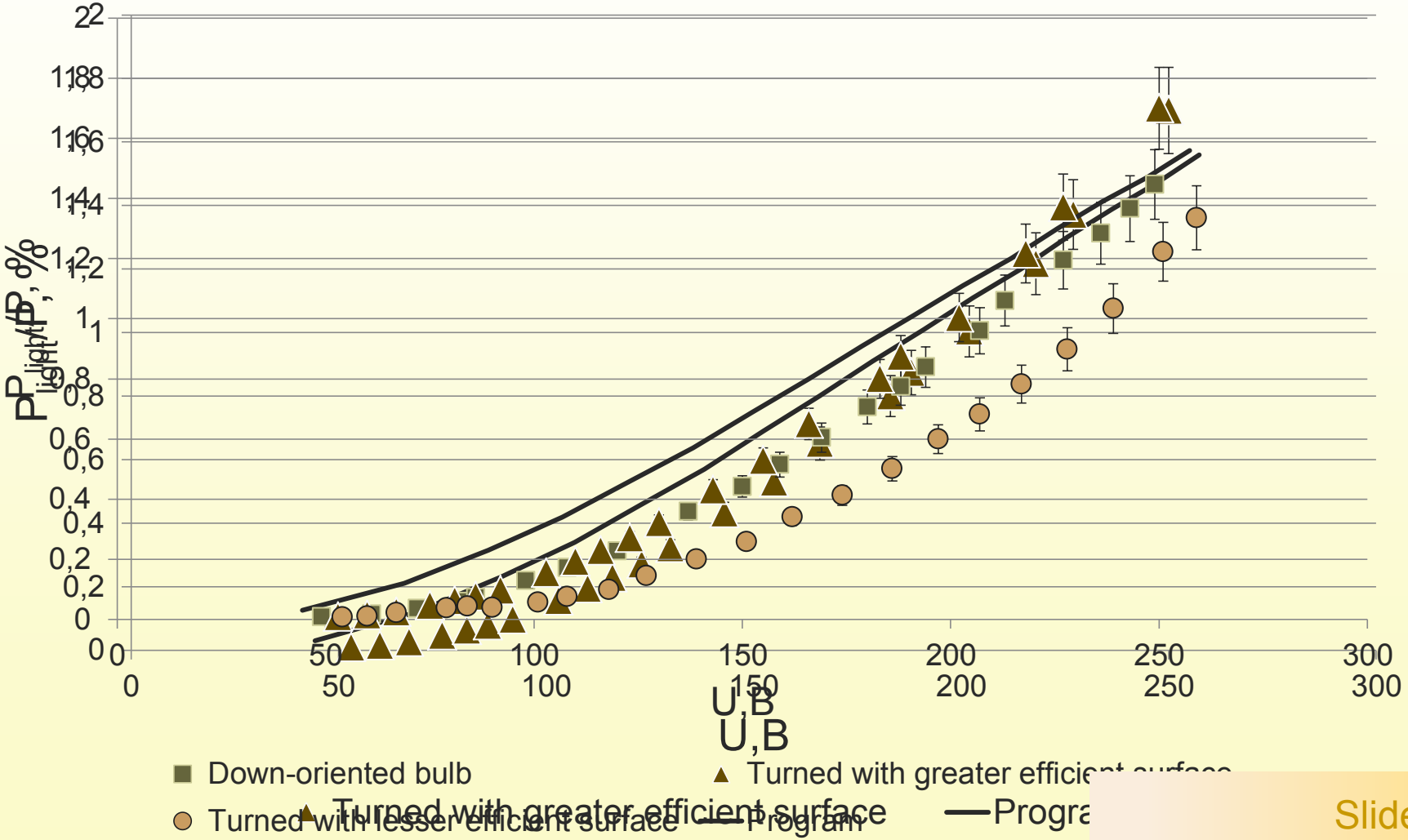
R – radiant emittance of visible light

5

$$P_{light} = R_{vis} \cdot S \cdot \varepsilon_{vis}$$

The power of light

The comparison of theory and experiment



Products of research

- Experiments under varied voltage and derivation of required ratio.
- A theoretical proposition with blackbody radiation as basis.
- Additional analysis and investigation of:
  - $\varepsilon(T)$ and $\varepsilon(\lambda)$ dependence;
  - $R(P)$ dependence;
  - $\rho(T)$ dependence.
- Programmed theoretical plot of required ratio.

References

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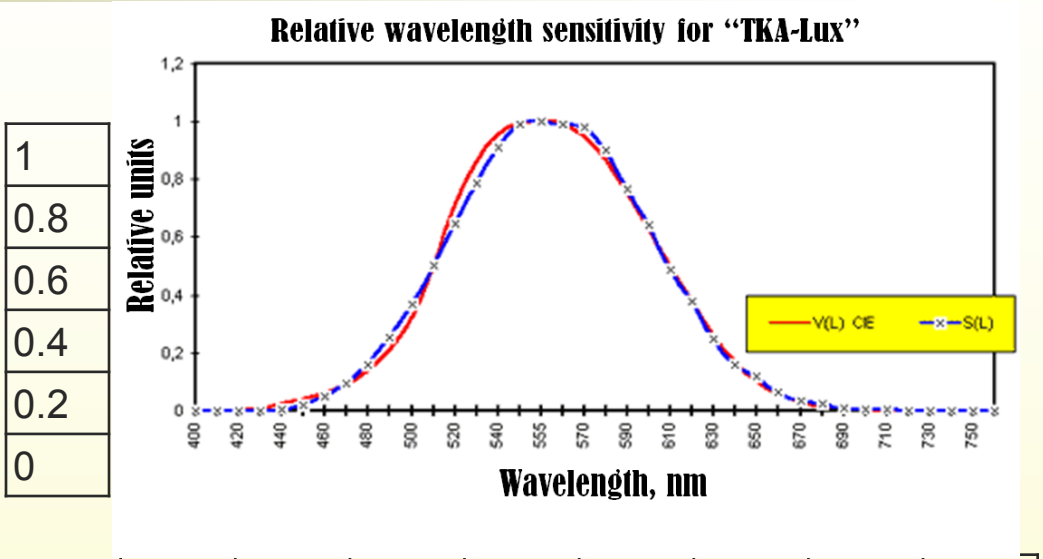
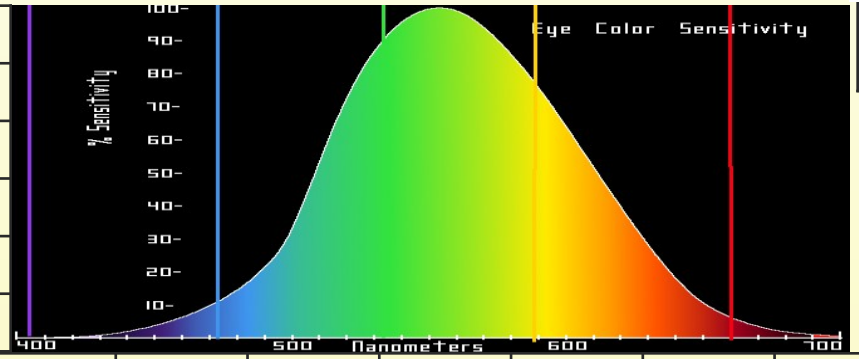
Thank you for your attention!

Additional info (slides)

The comparison of spectral sensitivity for the human eye and instruments of TKA-PKM series



1							
0.8							
0.6							
0.4							
0.2							
0							
	400	450	500	550	600	650	700	750



1							
0.8							
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0							
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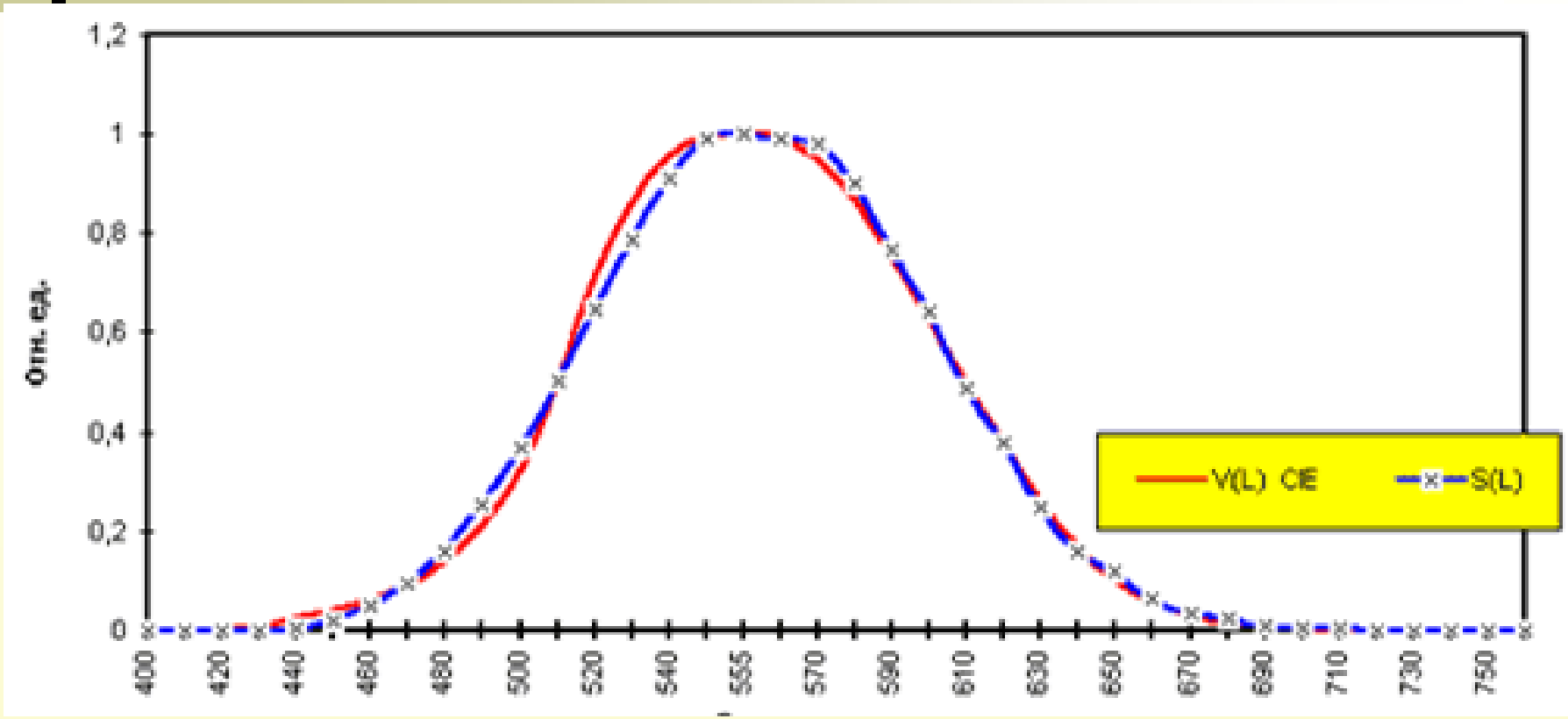
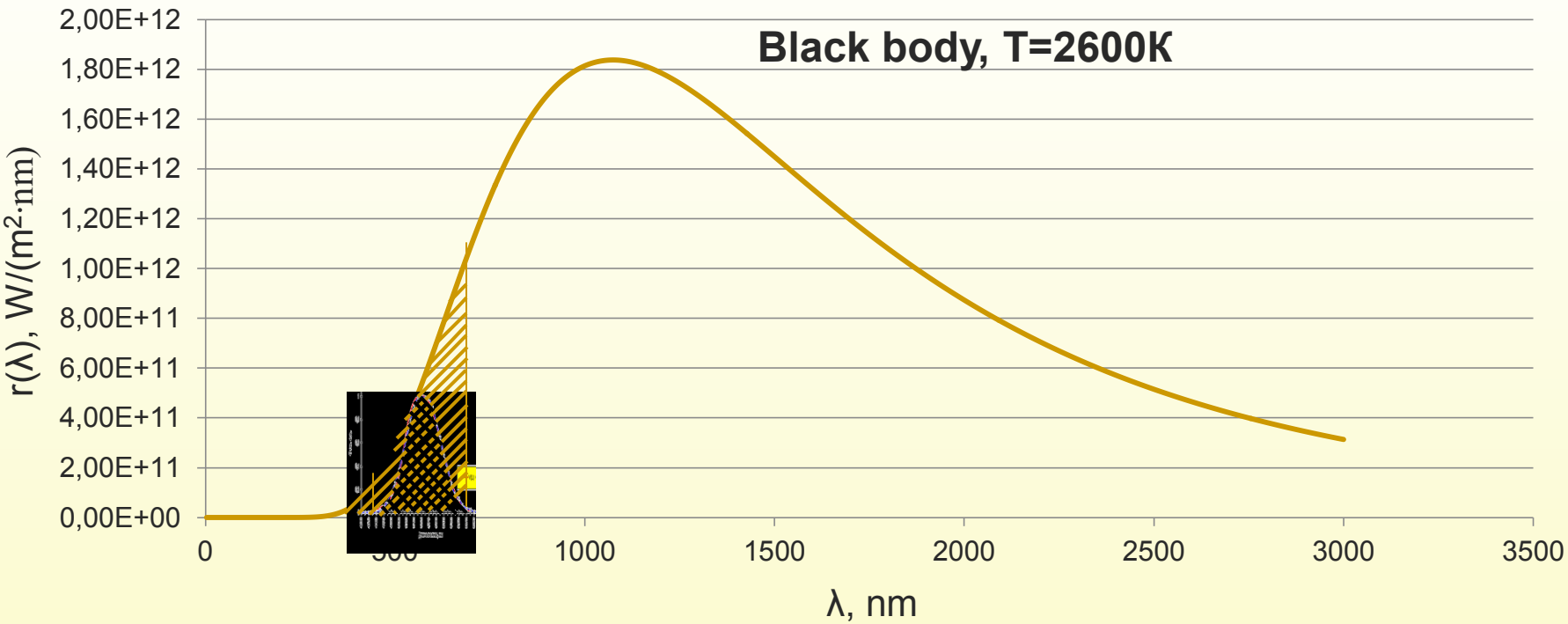
The comparison of spectral sensitivity for human eye and instruments of TKA-PKM series



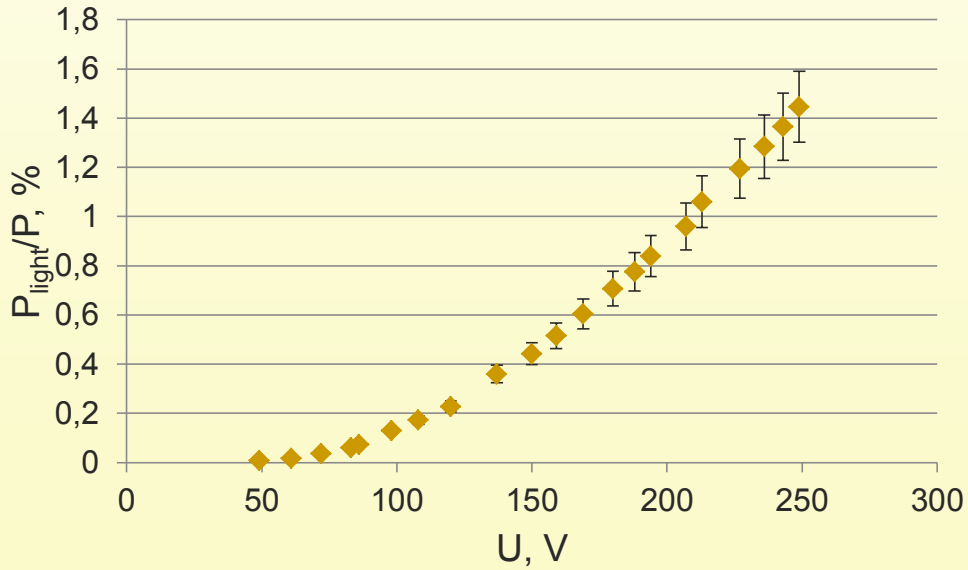
- The difference is negligible. Luxmeter distinguishes colors just like human eye does.

Visual comparison of radiant emittance, perceived by the instrument (either by human eye) and total 380-780nm radiation



The sample of experimental result

Bulb is down-directed									
L, m	$U_{bulb,}$ V	$U_{R,}$ V	R_R, Ω	I, A	**P_{full}, W**	E, lux	P_{light}, W	**$P_{light}/P_{full,}$ %**	R, Ω
15	49	2,6	20	0,13	**6,37**	1,2	0,000565	**0,0089**	376,92
	86	3,3	20	0,165	**14,19**	22	0,010362	**0,0731**	521,21
	137	4,3	20	0,215	**29,455**	225	0,105977	**0,3611**	637,21
	180	5	20	0,25	**45**	675	0,317931	**0,7115**	720
	213	5,6	20	0,28	**59,64**	1343	0,632565	**1,072**	760,71
	249	6,2	20	0,31	**77,19**	2370	1,116291	**1,4674**	803,23



The derivation of light power

$$E = \frac{\Phi}{S} = \frac{I\Omega}{S} = \frac{1}{683}\frac{P}{S};$$

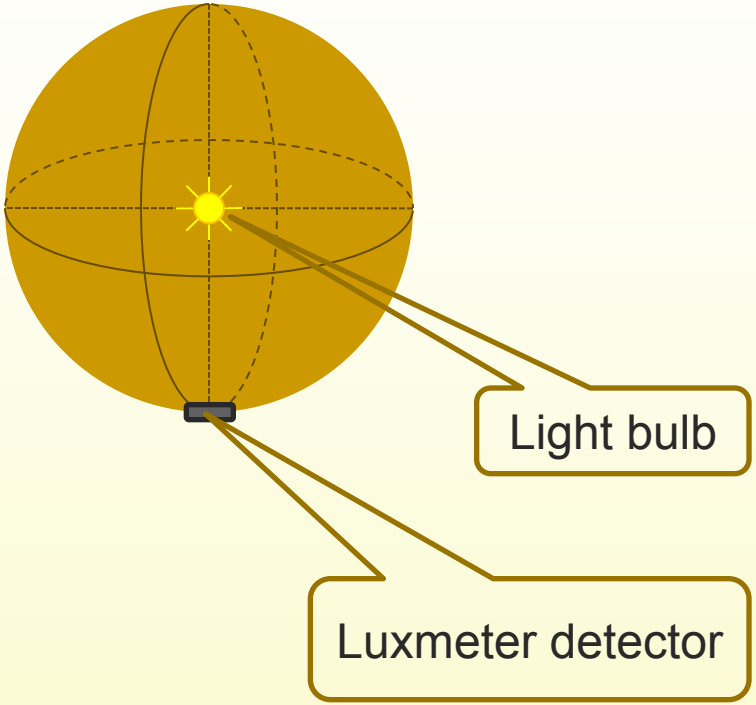
$$P = \frac{E}{683} \cdot S\,[W]$$

The bulb is a point light source which means :

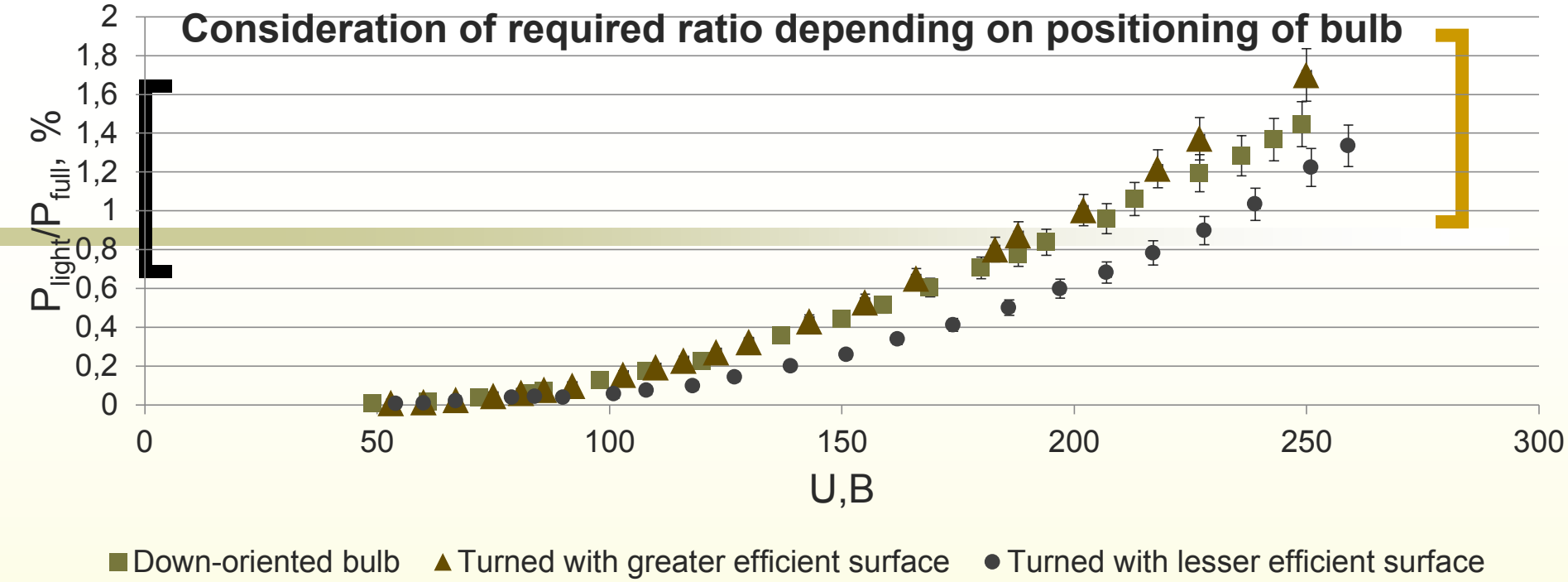
$$P_{light} = \frac{E}{683} \cdot 4\pi l^2, \text{ where}$$

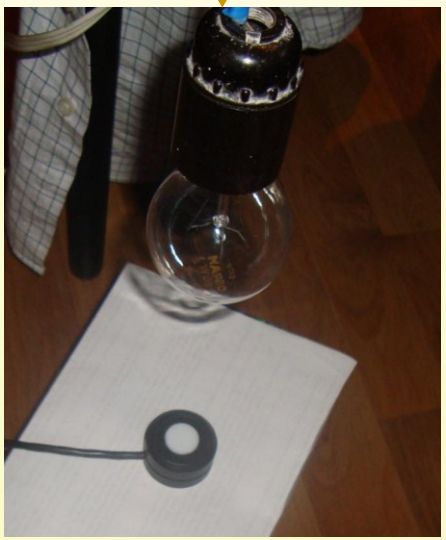
E is illumination

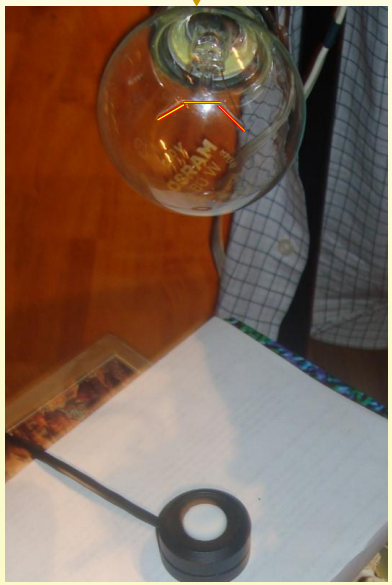
L is a distance between light and luxmeter detector



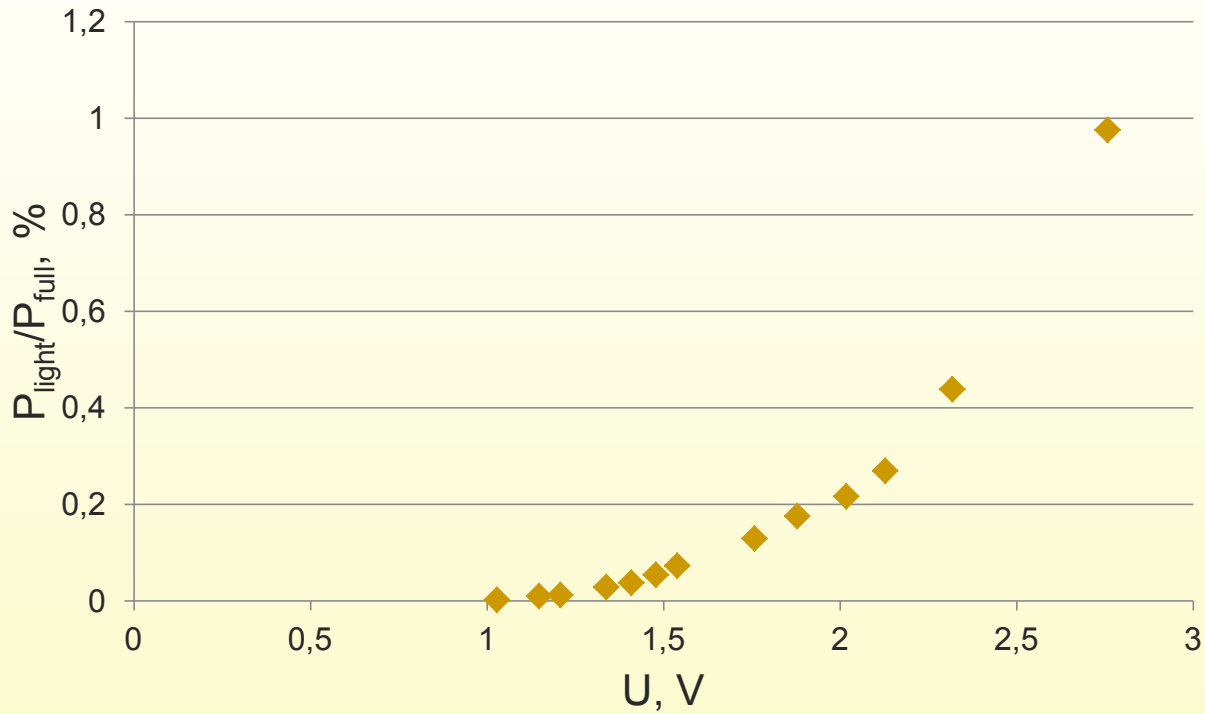
The bulb glows in almost the same way towards any direction. (It has been found out after several experiments)

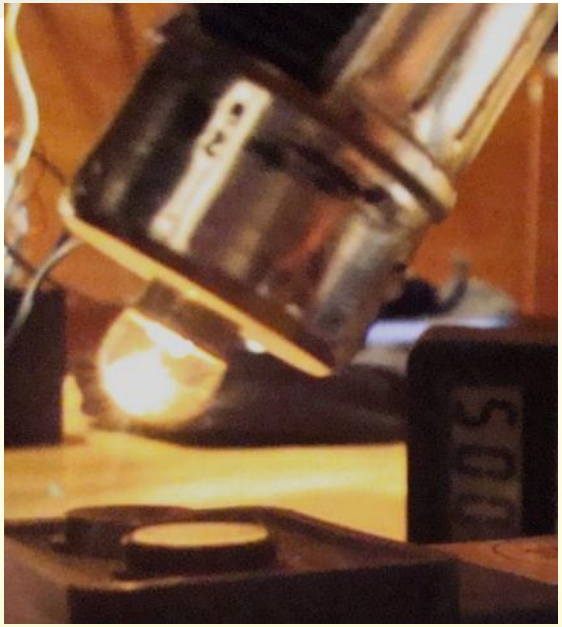

Consideration of required ratio depending on positioning of bulb
P_{light}/P_{full}, %
2
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
0
50
100
150
200
250
300
U,B
Down-oriented bulb
Turned with greater efficient surface
Turned with lesser efficient surface





The ratio for small bulb (675mW)





- For the rated voltage 2,5V the ratio is about 0.7%