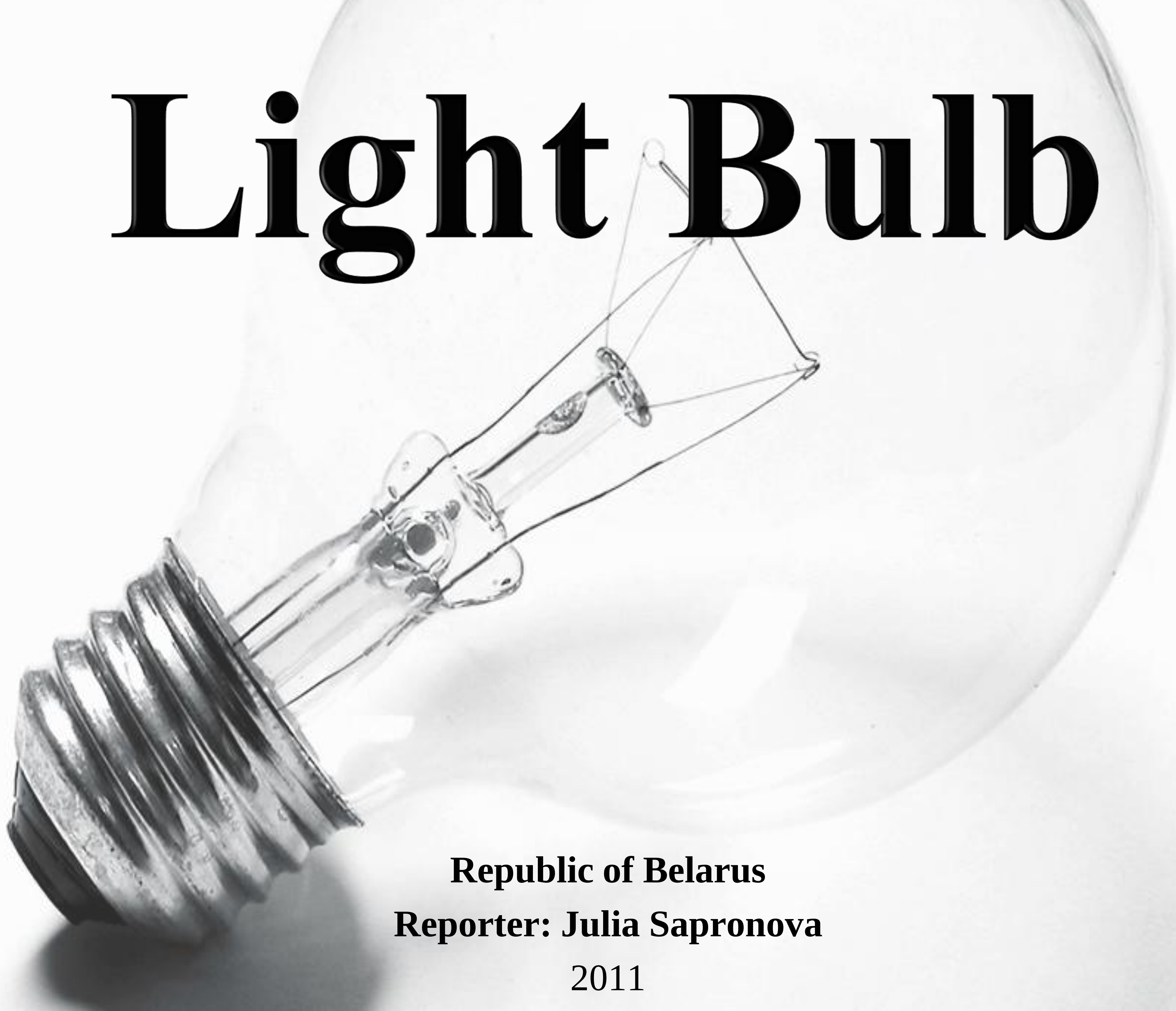
Light Bulb



Republic of Belarus

Reporter: Julia Sapronova

2011

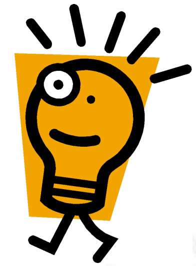
Light Bulb

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?

Plan of work

- Explanation of energy transfer and emission
- Theory
  - Optical part
  - Electrical circuit
- Experiment
- Conclusions

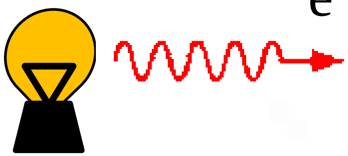
WHAT IS THE ENERGY SPENT ON?



$P_o = UI$

U – voltage

I – current



P_e

EMITTING

Light emitting

λ – (380nm; 780nm)

P_L

Infrared emitting

λ - (380nm; 200μm)

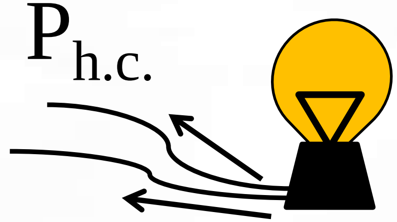
P_{inf}

Other emitting

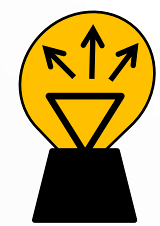
HEAT TRANSFER

Heat conductivity (in wires)

$P_{h.c.}$



Convection



The ratio between the thermal energy and light energy emitted from light bulb

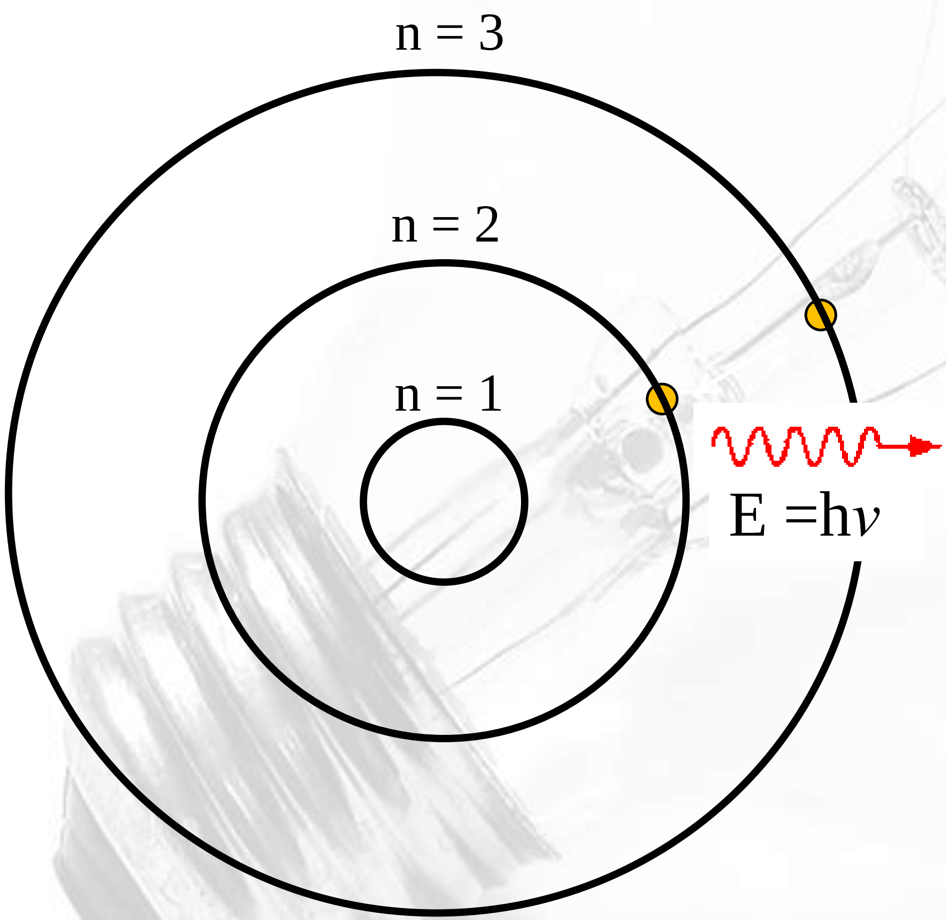
$$\gamma = \frac{P}{P_e}$$

Efficiency of a bulb

$$\eta = \frac{P_L}{P_o}$$

Equilibrium state

Formation of the emission



Atom gets extra energy

↓

Atom becomes excited

↓

Electron crosses from the highest to the lowest energy level and emits amount of energy - photon

Planck's law

Planck's law shows dependence of emission intensity on frequency of wave and temperature of emissive body

$$\varepsilon(v,T) = \frac{2hv^3}{c^2}\frac{1}{e^{\frac{hv}{kT}}-1}$$

ε is emissive intensity of blackbody near the light source;
ν is frequency; **T** is temperature of emissive body;
h is Planck's constant; **k** is Boltzmann constant;
c is speed of light;

Planck's law for wavelength

$$\varepsilon(\nu)d\nu = \varepsilon(\lambda)d\lambda$$

$$\Downarrow$$

$$\varepsilon(\lambda) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda kT}} - 1}$$

Determination the emissive power using Planck's law

Emissive power in range of wavelength from to λ_i to $(\lambda_i + d\lambda)$

$$P = \varepsilon(\lambda)d\lambda$$

$$P_{vis} = \int_{380nm}^{780nm} \varepsilon(\lambda)d\lambda$$

Emissive power of visible emission

$$P_{inf} = \int_{780nm}^{2700nm} \varepsilon(\lambda)d\lambda$$

Emissive power of infrared emission

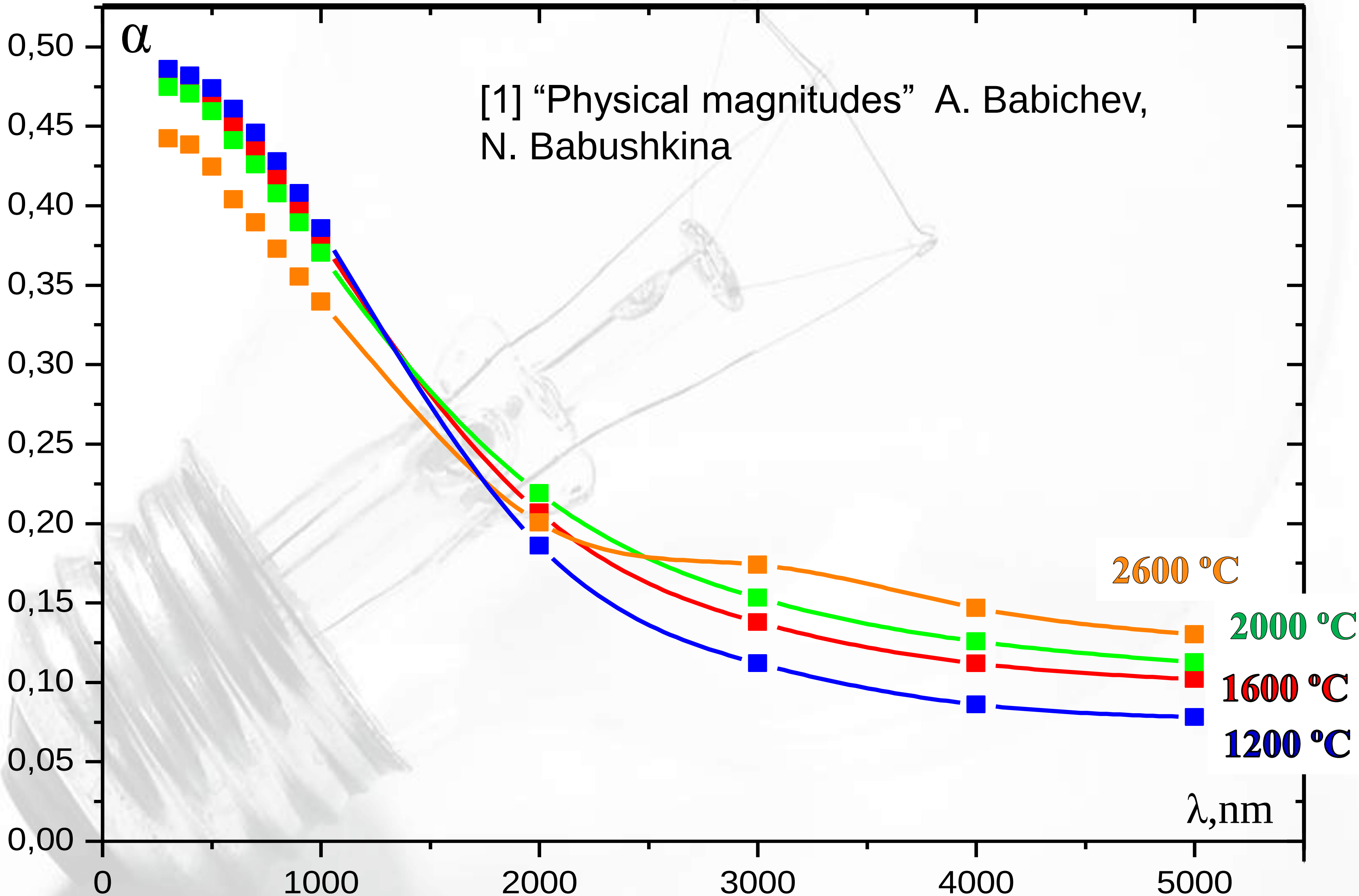
Blackbody

A **blackbody** is an idealized physical body that absorbs all incident electromagnetic radiation

Real body

α is emissivity

α(λ) for different temperatures of tungsten filament

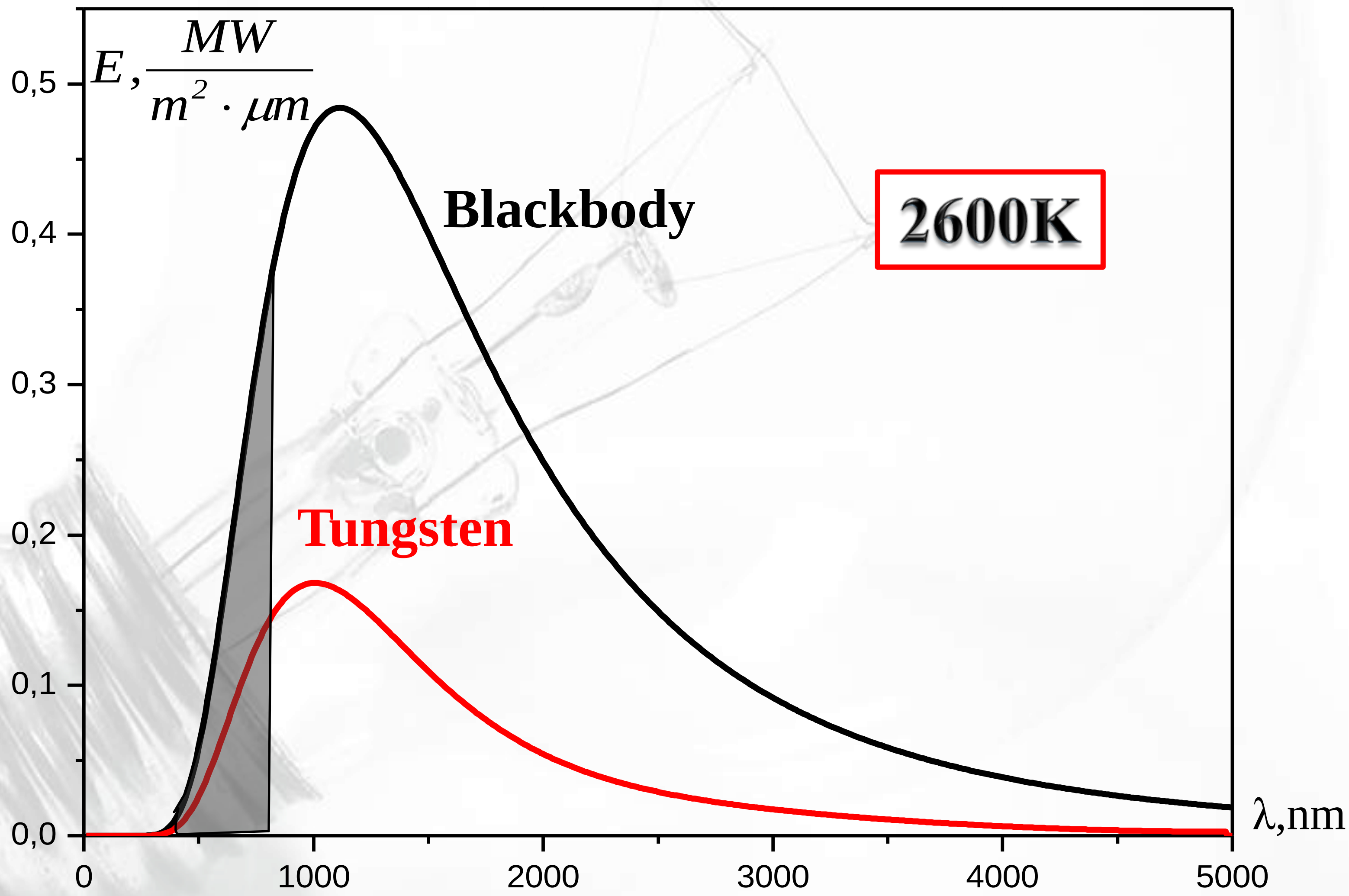


Dependence E(λ) for not blackbody

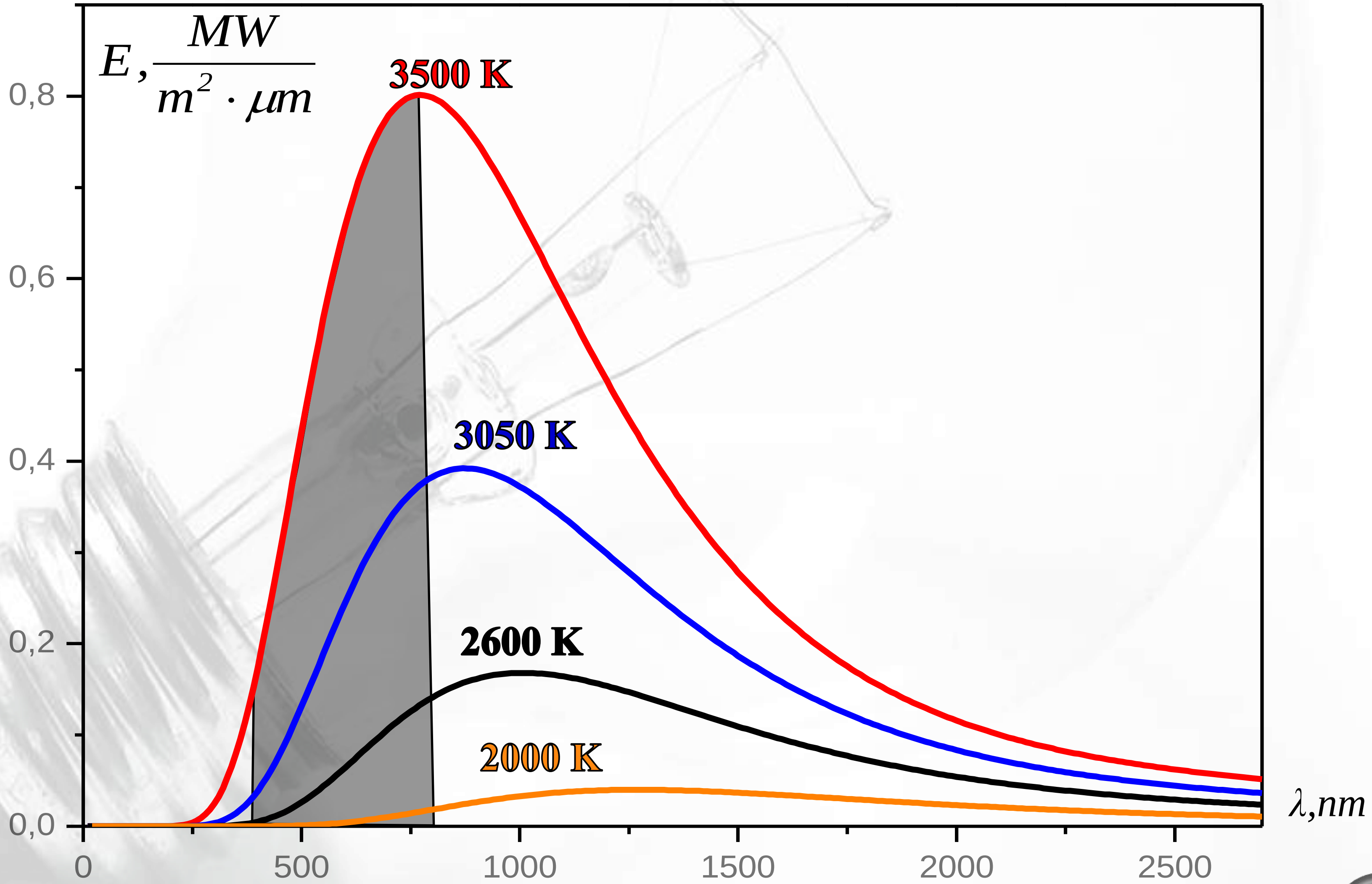
$$E(\lambda)=\alpha(\lambda,T)\varepsilon(\lambda,T)=\alpha(\lambda,T)\frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda kT}}-1}$$

α(λ,T) is emissivity of tungsten which depends of the wavelength of emission and temperature of emissive body

Comparison of the emission intensity of tungsten and blackbody

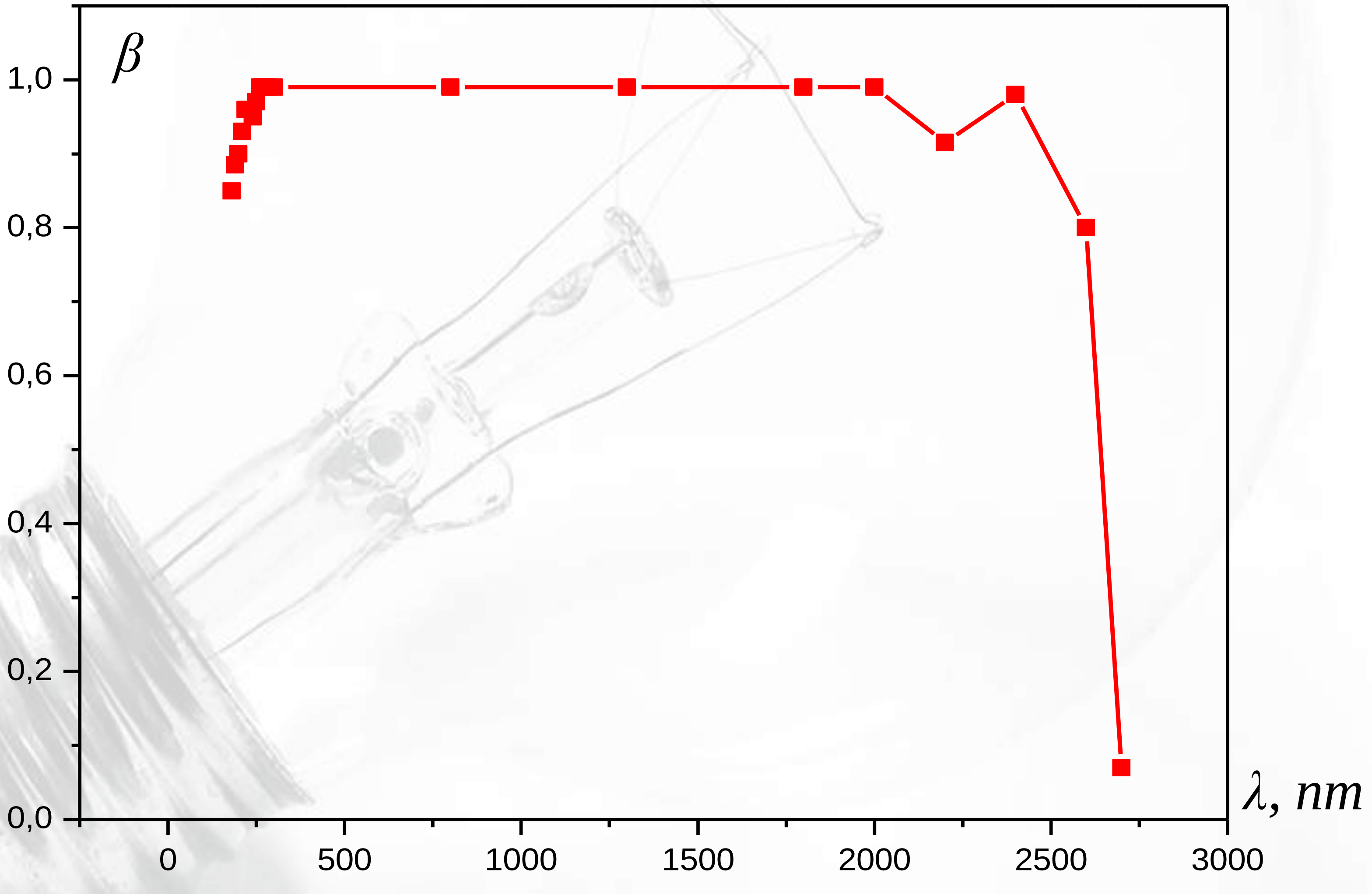


Emission intensity on the wavelength for tungsten

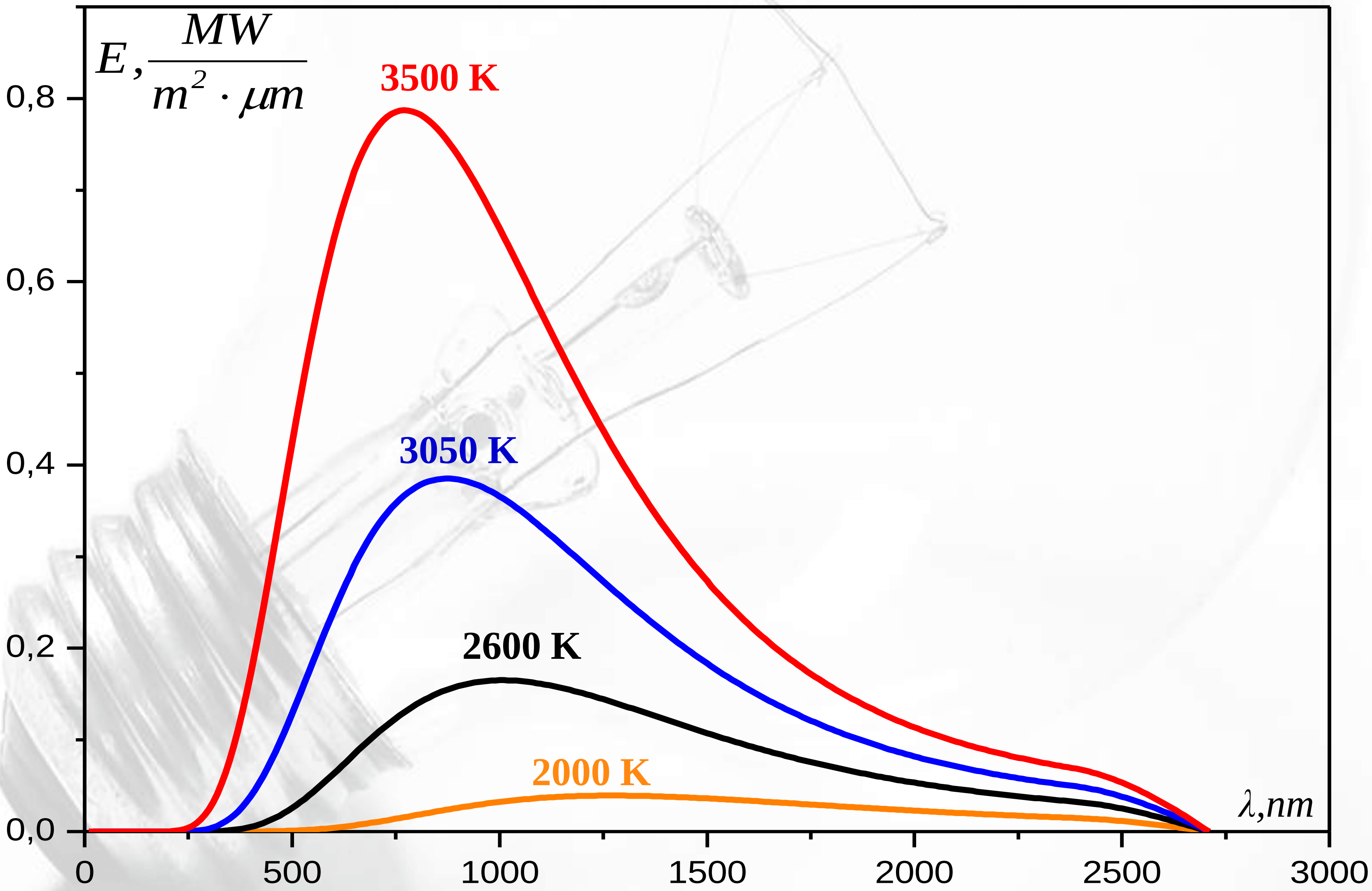


Light bulb without glass

Transmissivity of the glass for different wavelength



Dependence of emission intensity on the wavelength for light bulb



Calculation of γ

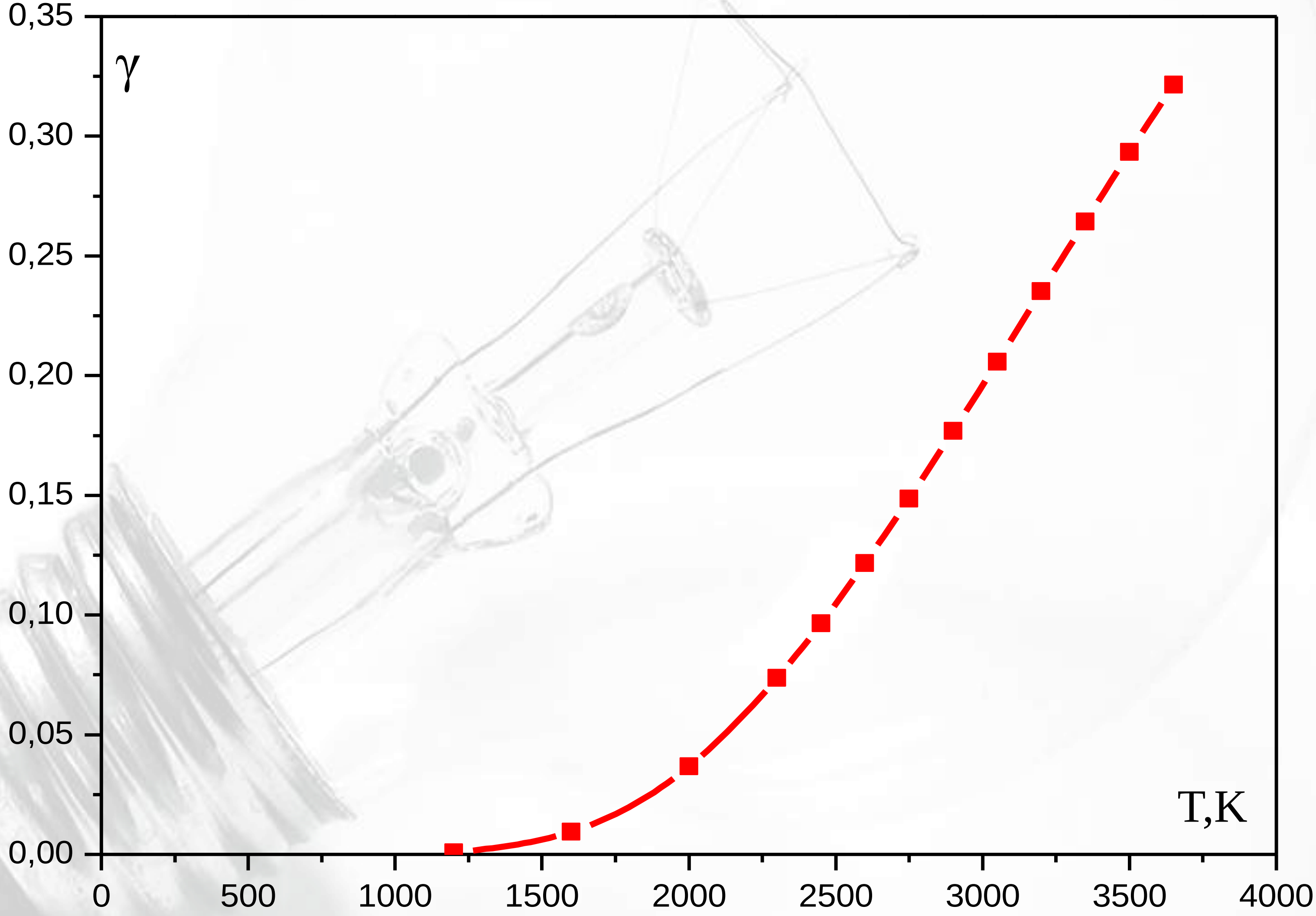
$$\gamma = \frac{\int_{380nm}^{780nm} \alpha(\lambda, T)\beta(\lambda)\varepsilon(\lambda)d\lambda}{\int_{380nm}^{2700nm} \alpha(\lambda, T)\beta(\lambda)\varepsilon(\lambda)d\lambda}$$

ε is emission intensity of blackbody;

α is emissivity of tungsten;

β is glass transmissivity;

Theoretical dependence of γ on the temperature of the tungsten filament



Making the dependence γ(u)

$$UI = P_c + P_t + P_e$$

Difficult to estimate precisely

U is voltage; **I** is current;

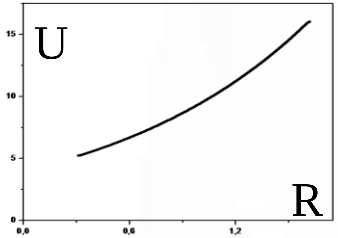
P_c is power of convection heat transfer;

P_t is power of thermal conductivity heat transfer;

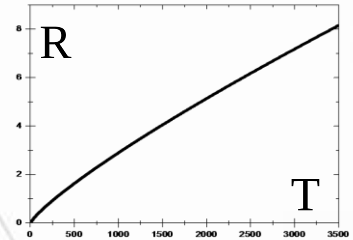
P_e is emissive power

Making the dependence γ(u)

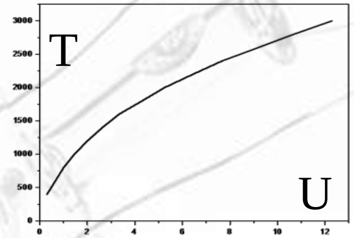
The dependence U(R)



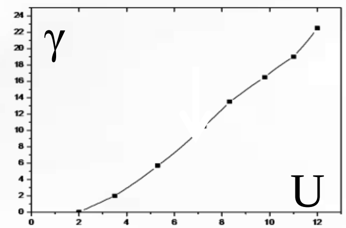
The dependence R(T)



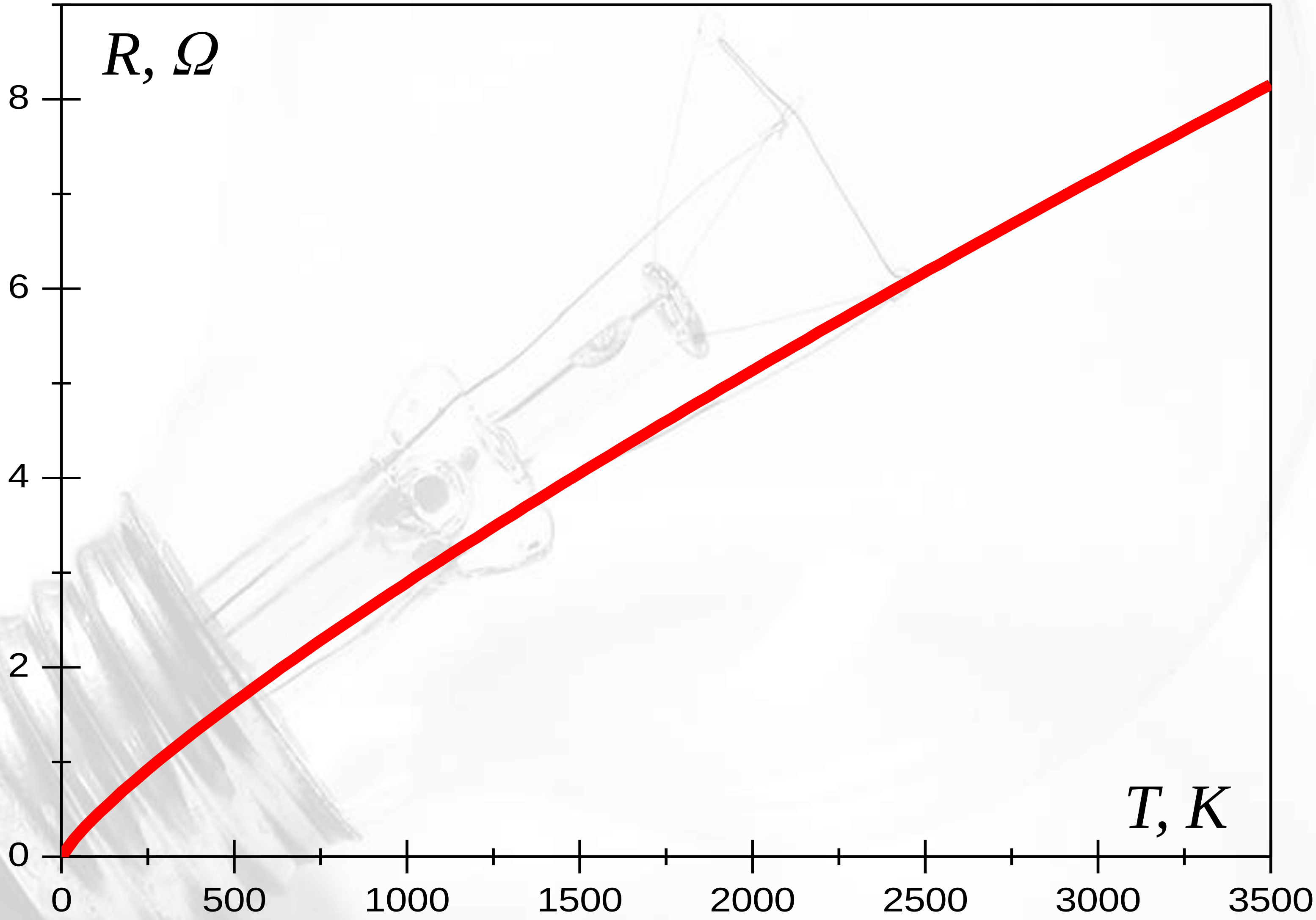
The dependence T(U)



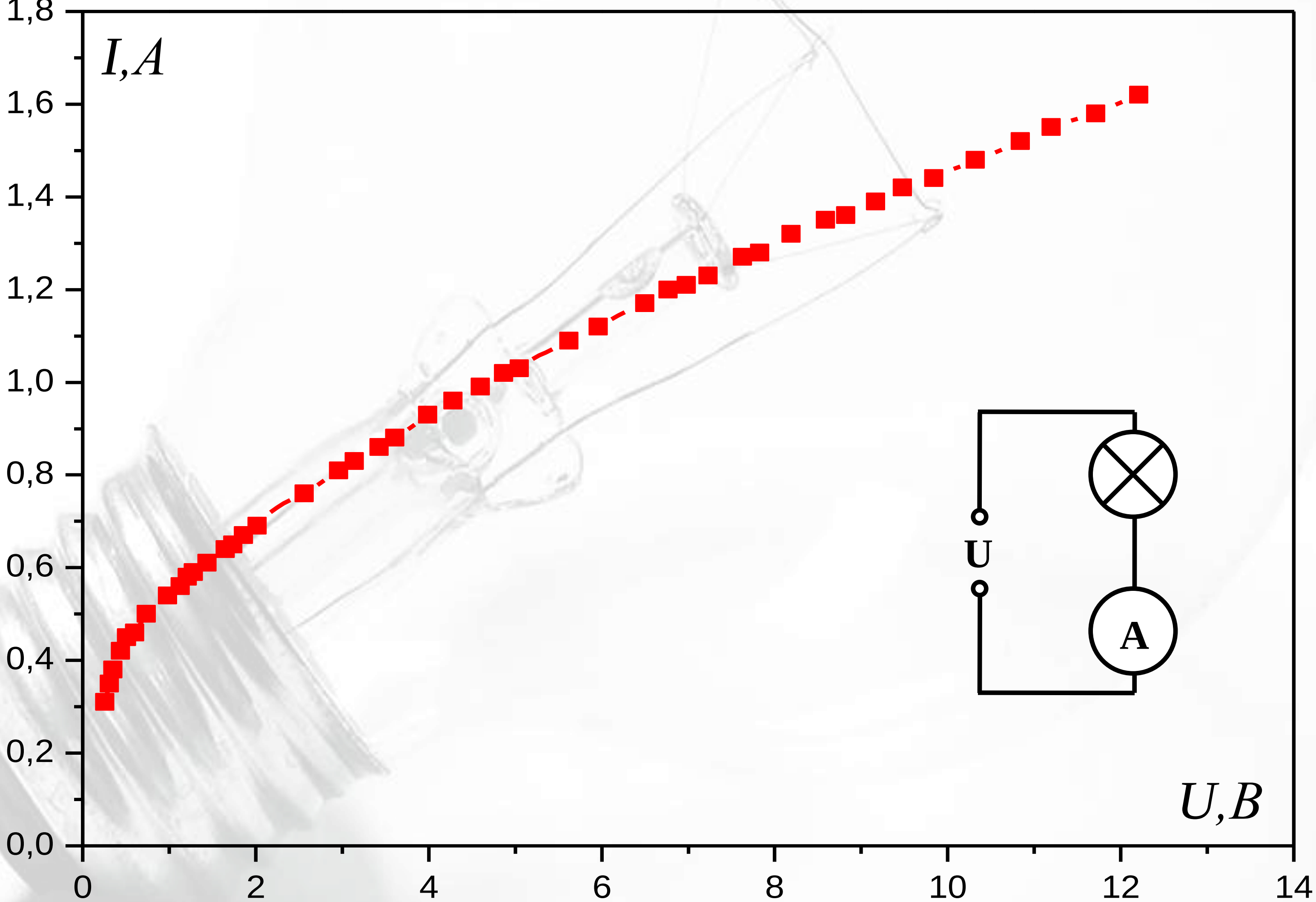
The dependence γ(U)



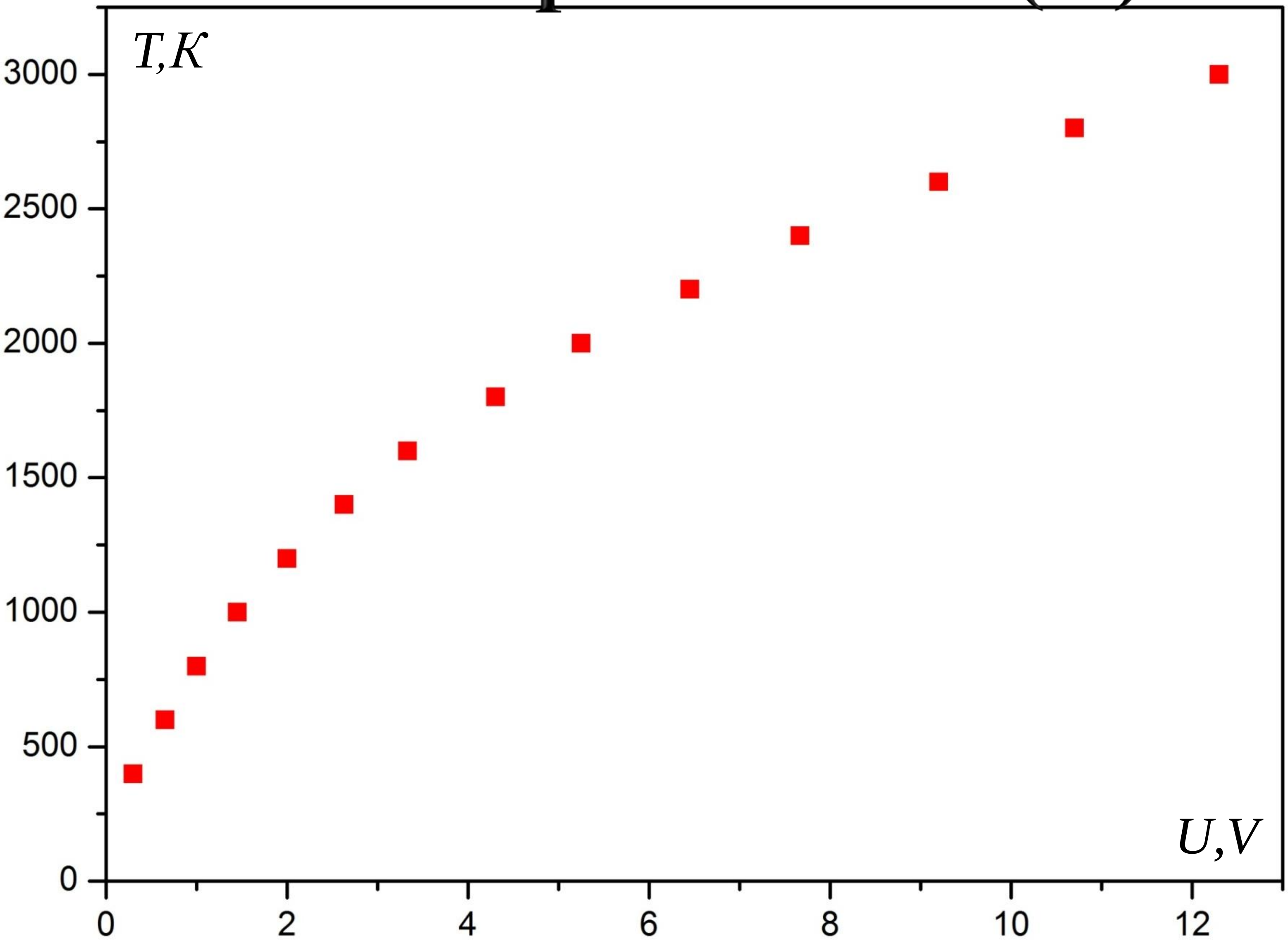
The dependence R(T)



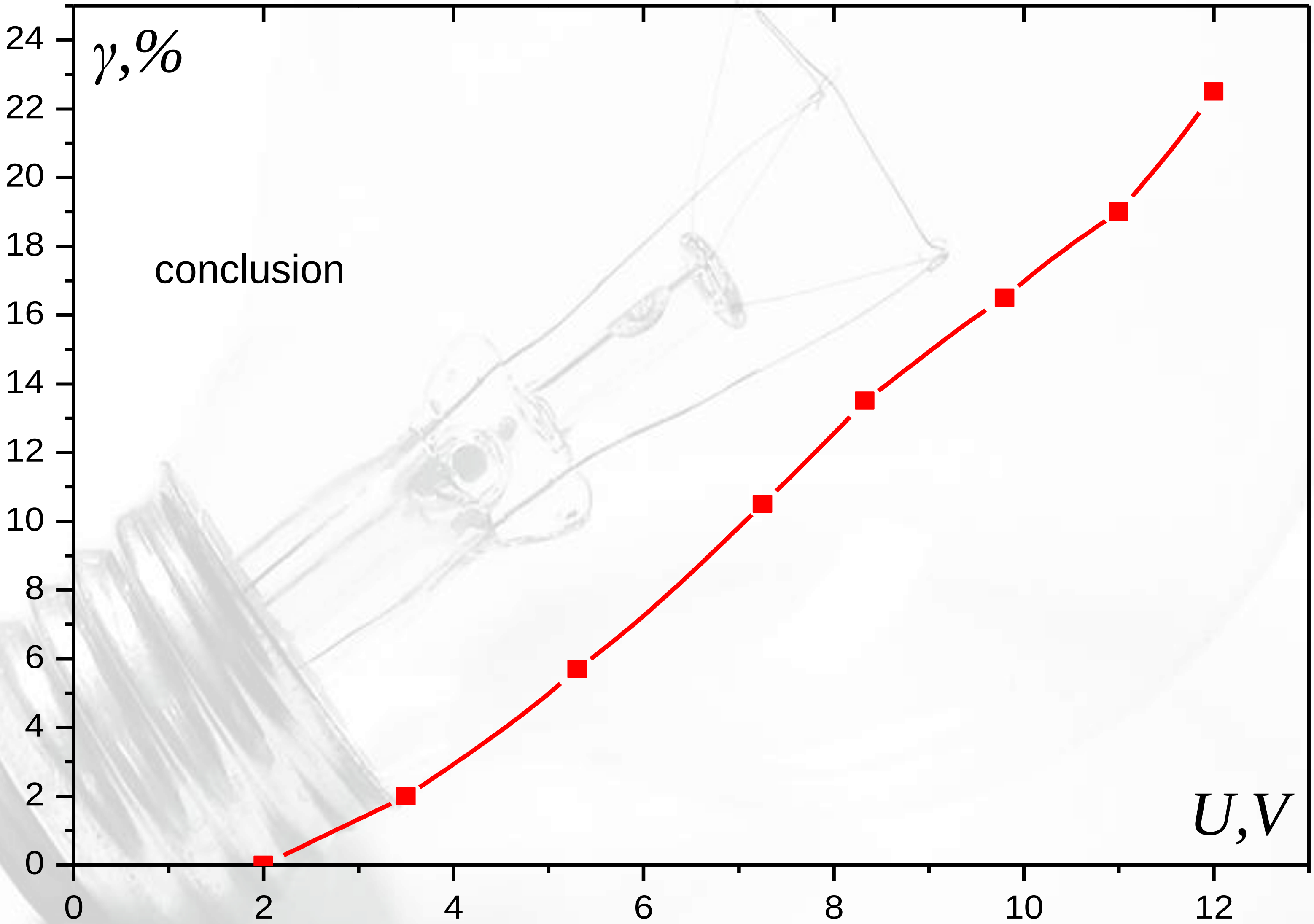
Volt-ampere characteristic for light bulb



The dependence T(U)

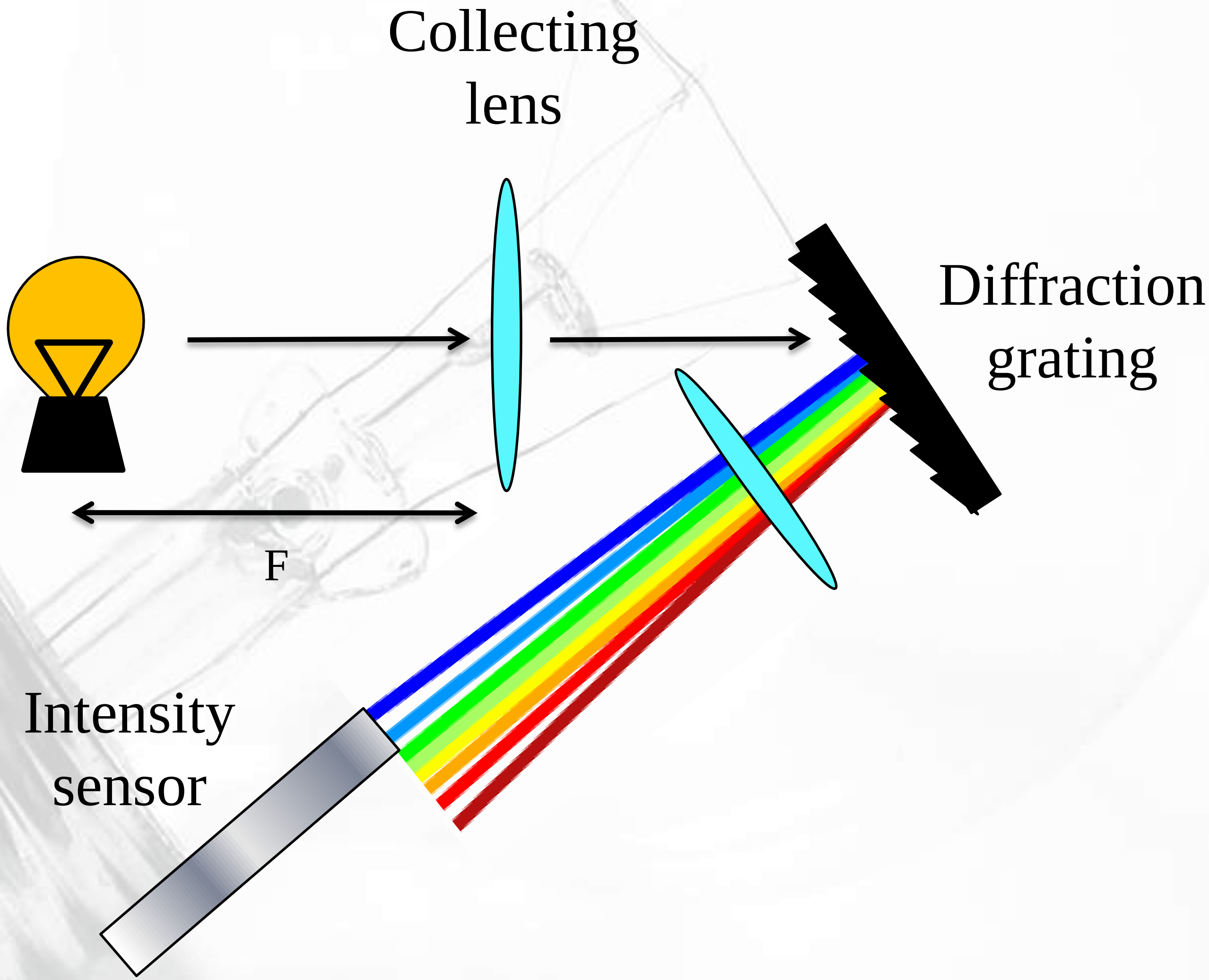


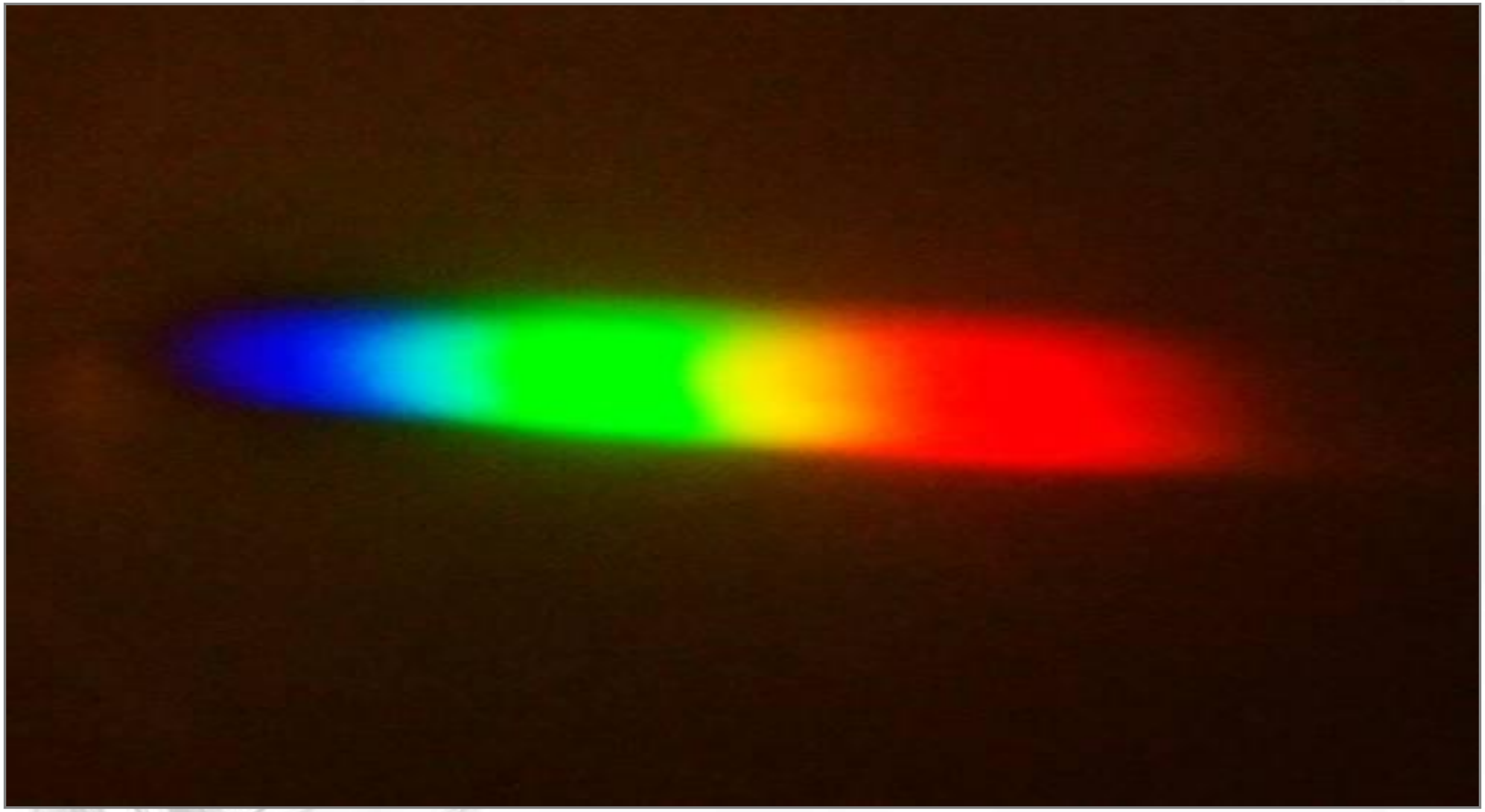
THEORETICAL DEPENDENCE γ(U)



Explanation | Electrical circuit | Experiment | Conclusions

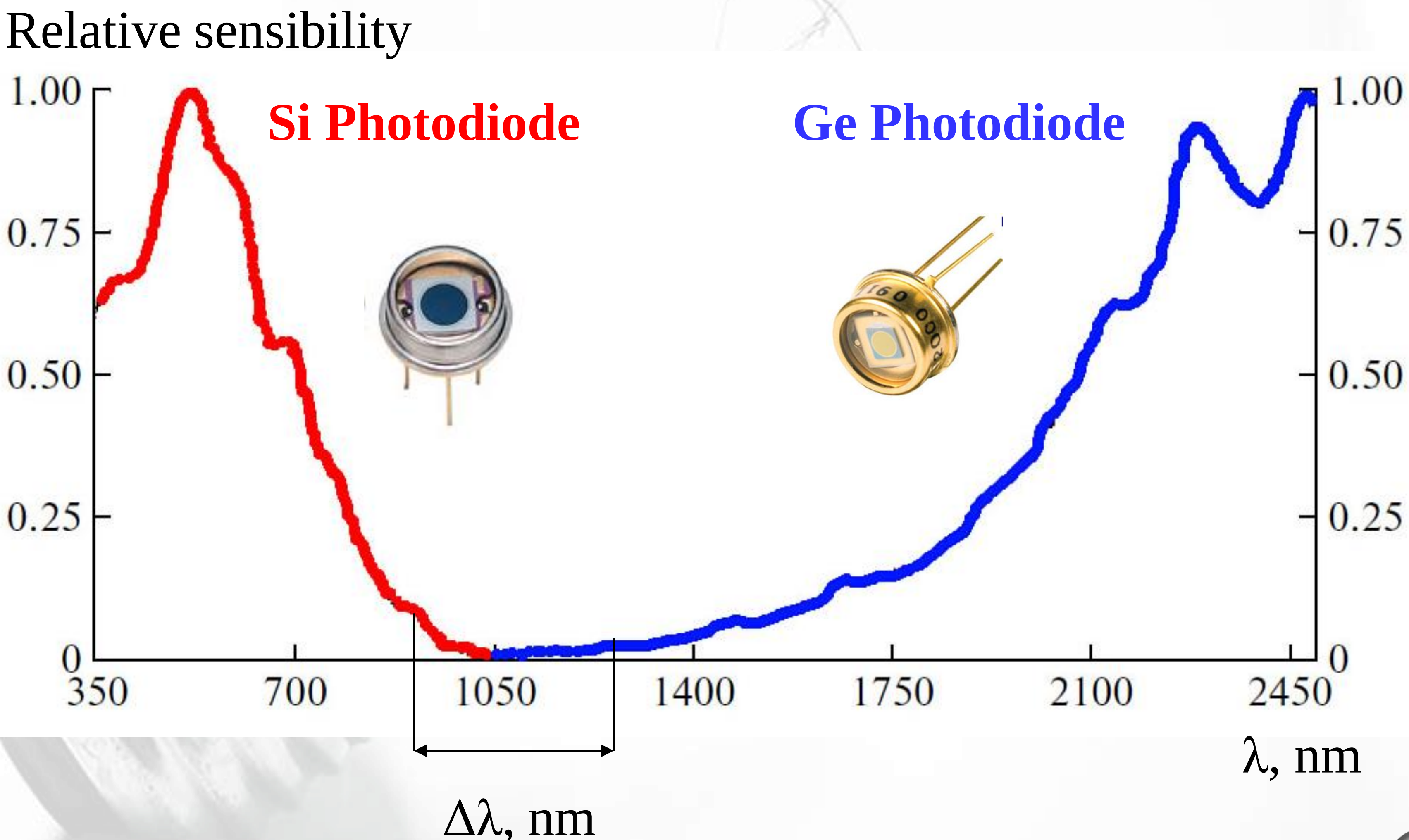
EXPERIMENTAL SETUP



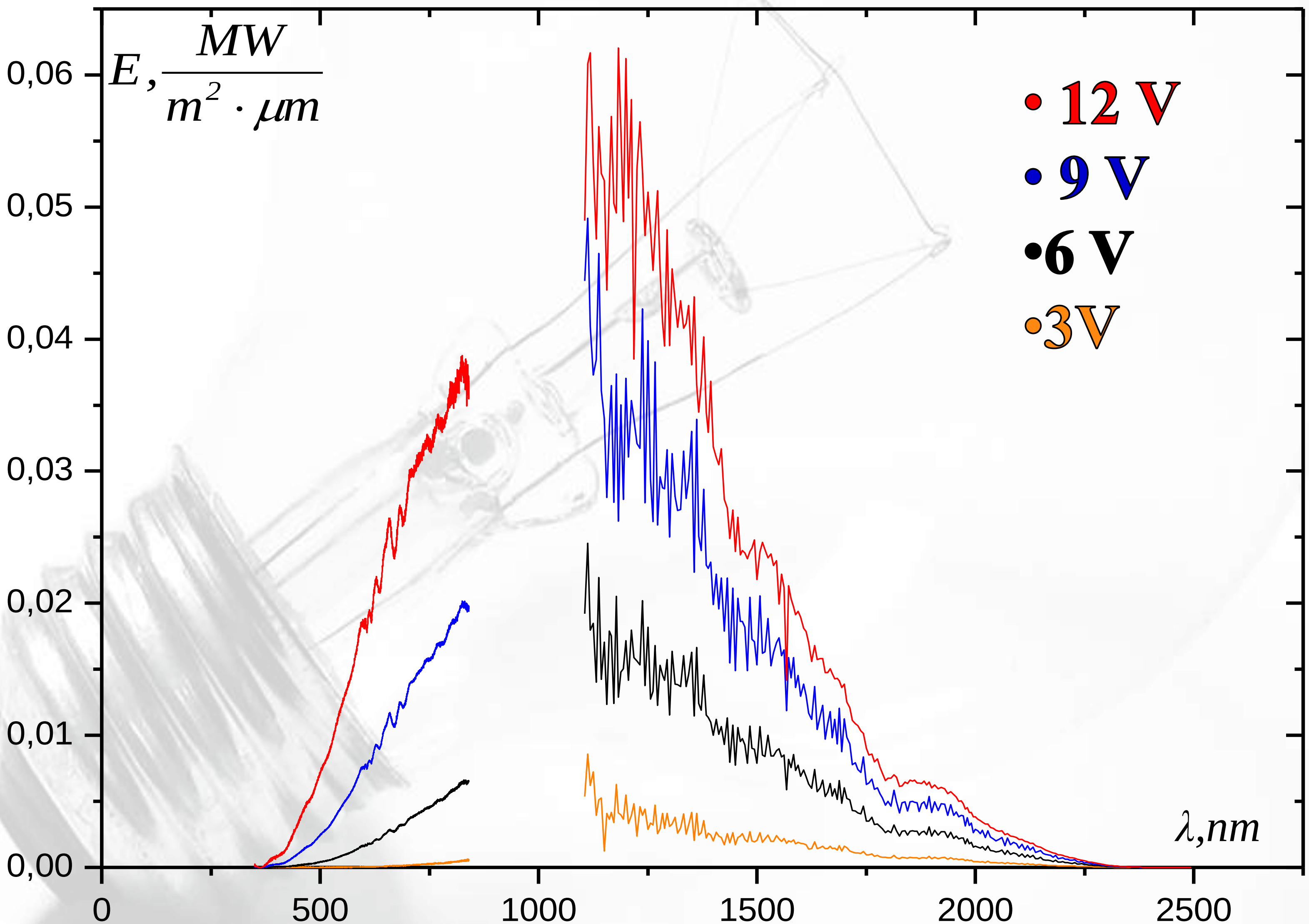


Spectrum obtained from light bulb using collecting lens and diffraction grating

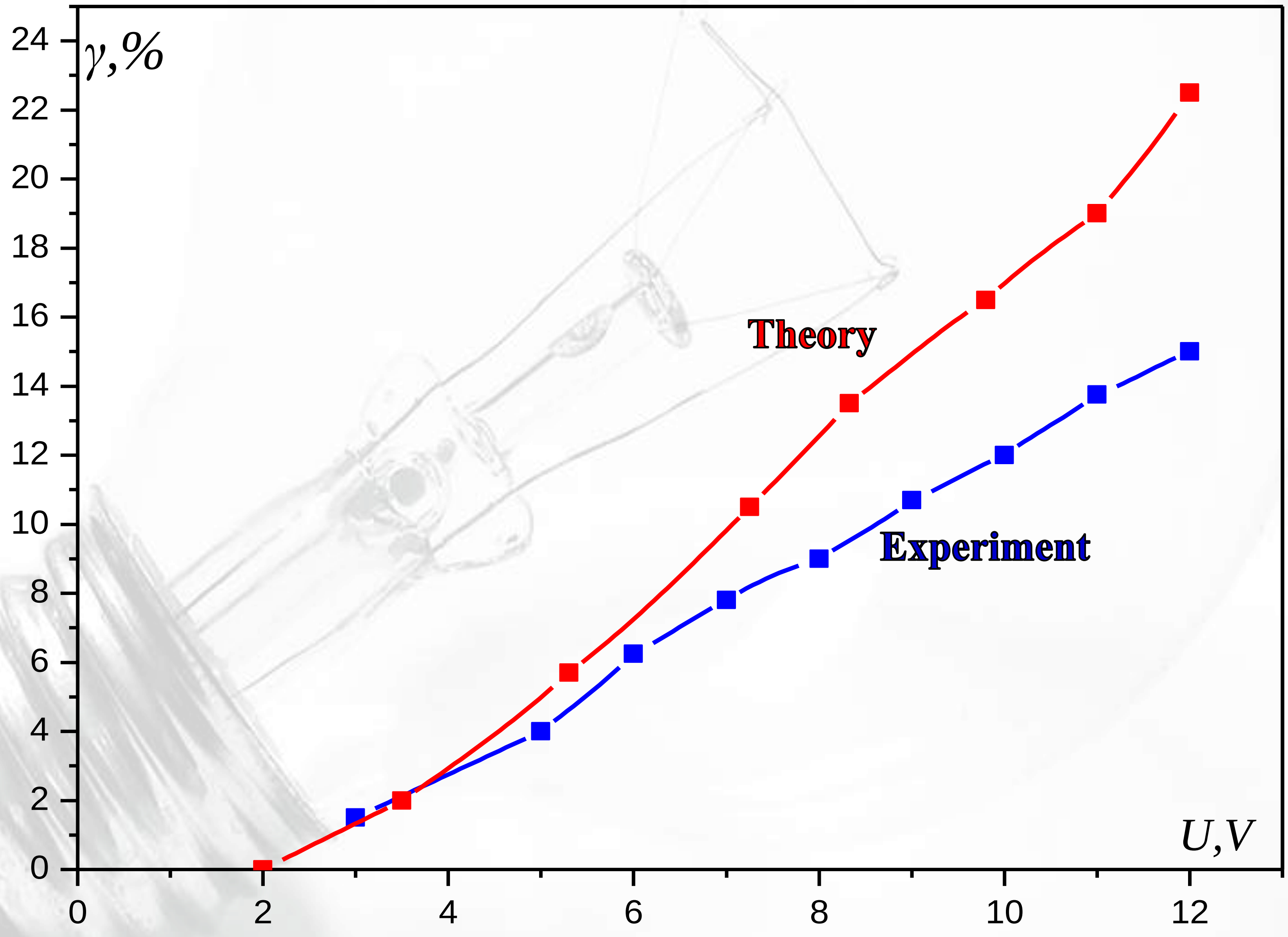
Intensity measurement



Experimental dependence E(λ)

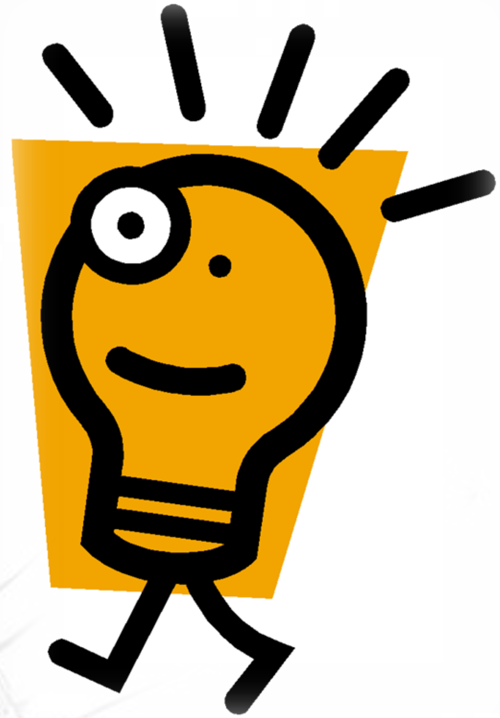


Comparison of theory and experiment



CONCLUSIONS

- The Planck's law can be used for description of emission of a light bulb but emissivity of tungsten and transmissivity of glass should be considered
- Ratio between thermal and light energy emitted from a light bulb depends only on the temperature of the tungsten filament
- Voltage must be increased for increasing the ratio between thermal and light energy
- The rated voltage is the optimal voltage for light bulb
- Maximal ratio between thermal and light energy for bulb with rated voltage 12V is $\gamma=15\%$



THANK YOU FOR YOUR ATTENTION

Team is supported by Kayson Belarus

DETERMINATION OF THE TEMPERATURE OF TUNSTEN FILAMENT

$$R = R_0 \left(\frac{T}{T_0}\right)^{1.21}$$

R_o – electrical resistance for the temperature T_o

T_o = 293 K
R_o = 1,05 Ω