LETTER TO THE EDITOR

Response to ‘Further thoughts on the solar constant’

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Response to 'Further thoughts on the solar constant'

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This is response to [1] by Frank Thompson, discussing the nature of the function describing the temperature dependency of heated bolometer.

In [2] we are stating that for the estimation of the solar constant we can use formula

$$I_{SC} = \frac{mc\Delta T}{S\Delta t}, \tag{1}$$

which can be rearranged as

$$T = T_0 + \frac{I_{SC} S\Delta t}{mc}.$$

The directive is proportional to the absorbed energy (in the form of intensity of electromagnetic radiation I_{SC}) and to the area S of the bolometer and inversely proportional to the thermal capacity c. This is sensible, but it is obvious that the temperature cannot rise to infinity.

We have to take into account the empirical law of thermal conductivity

$$\frac{\Delta E}{\Delta t} = \frac{\lambda S'}{d}(T - T_{amb}),$$

where λ is the coefficient of thermal conductivity, S' is the contact area and d is the thickness of the air layer. Thermal conductivity and geometrical properties of the bolometer can be denoted G ($G > 0$). Then we have for the energy losses

$$\frac{dT}{dt} = \frac{I_{SC}}{C_s} - \frac{G}{C_s}(T - T_{amb}),$$

where $C_s = \frac{mc}{S} \approx 16\,100\ \mathrm{J \cdot m^{-2} \cdot K^{-1}}$. Then we have to solve non-homogeneous linear differential equation

$$\frac{dT}{dt} + \frac{G}{C_s}T = \frac{I_{SC}}{C_s} + \frac{G}{C_s}T_{amb}. \tag{2}$$

The solution is

$$T = T_0 e^{-\frac{Gt}{C_s}} + \left(\frac{I_{SC}}{C_s} + T_{amb}\right)\left(1 - e^{-\frac{Gt}{C_s}}\right). \tag{3}$$

It is interesting how such a simple thing as bolometer heating can get complicated. If we fit this function to the measured data (see figure 1), we get

$$I_{SC} = 570\ \mathrm{W \cdot m^{-2}},$$
$$G = 83.9\ \mathrm{W \cdot m^{2} \cdot K^{-1}},$$

where the value of I_{SC} is close to the value calculated in [2] by equation (1), where the exponential curve is substituted with linear dependency and by two other methods therein.

We are well aware of this not-very-simple solution of equation (2) and we deliberately choose to neglect this for the sake of simplicity. The laboratory exercise described in [2] is intended for secondary school, where Newton's law of heating/cooling is not known to students (in some cases, even exponential functions does not need to be known to them also) and the rigorous solution does not provide a much better result. That is why we also did not publish the method similar to this, but using a vacuum pump to suck the air out from glass jar with a bolometer, effectively reducing heat losses (figure 2). It yields a slightly better result ($I_{SC} = 630\ \mathrm{W \cdot m^{-2}}$), but the measurement is

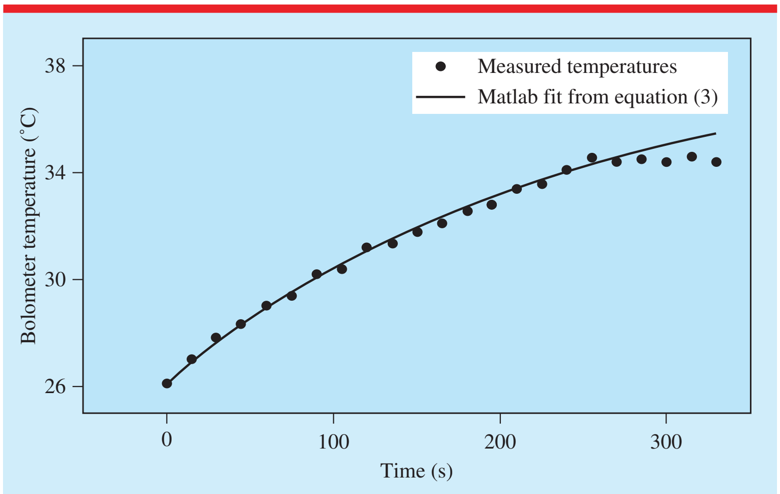

Figure 1. Bolometer temperature versus time curve fitted from equation (3).

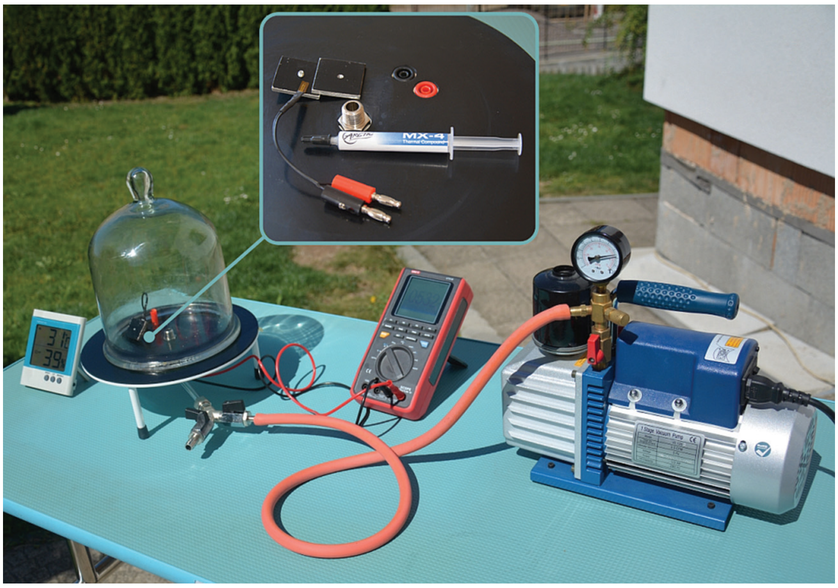

Figure 2. Bolometer with thermocouple and vacuum pump.

much more complicated (the temperature has to be measured with a thermocouple, the measurement have to be done very quickly, because the temperature increase melts the Ramsay grease and the system losses air tightness, some radiation is reflected and some is absorbed by the thick walls of the glass jar etc).

The key feature of this laboratory exercise is it is a quick and simple application of physics laws already known to students to support the teaching of astrophysics, even if the final value is far from the tabular one. That is why the paper was titled 'estimation' of the solar constant.

It should be noted that from the 1360 $W \cdot m^{-2}$ available at the upper boundary of the Earth's atmosphere some 30% are reflected (∼4% by the Earth's surface.) and scattered (by the air molecules but also by water vapour, dust, haze and smog particles) back to space. Around 20% is absorbed when the radiant energy is transferred to the air molecules, which causes heating of the atmosphere that peaks at about 50 km (the stratopause). Details can be found in [3].

Even with no clouds, the actual value is close to that obtained during the experiment with a vacuum pump, taking into account that only the UV part of the Sun spectra is considerably absorbed by the glass (only 6.5% of the total energy is contained in the ultraviolet region).

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References

[1] Thompson F 2018 Further thoughts on the solar constant *Phys. Ed.* **53** 036501
[2] Břízová L and Šlégr J 2017 Estimation of the solar constant with simple bolometer *Phys. Ed.* **52** 013008
[3] Kump L R, Kasting J F and Crane R 2003 *The Earth System: an Introduction to Earth Systems Science* 2nd edn (Upper Saddle River, NJ: Prentice-Hall) p 351