statistical physics → statistics of radiation ★★

Efficiency of a Solar Cell

In this problem, we will show that simple physics constrains the efficiency of a solar cell. Consider a planar solar cell with a flux Φ of photons per second, coming from the sun, which radiates as a black body at temperature T_S.

(a) Suppose that the solar cell can only absorb radiation quanta from the sun with an energy greater than ϵ. Given the spectrum of radiation from the sun (treat it as a blackbody) what is the probability that a quantum of radiation will be absorbed? Call this number ρ, and show that it only depends on $\epsilon/k_\mathrm{B}T_\mathrm{S}$.

(b) Approximate that each photon that is incident produces an energy ϵ for use by the solar cell. By considering the typical energy of an incident photon, show that the efficiency η of the solar cell is given by

$$\eta = \frac{30\zeta(3)}{\pi^4}\frac{\epsilon}{k_\mathrm{B}T_\mathrm{S}}\rho\left(\frac{\epsilon}{k_\mathrm{B}T_\mathrm{S}}\right).$$

Numerically determine the maximum value of η. Given $T_\mathrm{S} = 6000$ K, what is the value of ϵ for a optimal solar cell (in terms of η)?

People are now able to build solar cells (although they are quite expensive to do) which reach the theoretical limit on efficiency that you found in part (b). For comparison, coal/oil/nuclear power plants tend to have efficiencies of about 30%.