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Experimental physics Vb (particle and astro-physics)

Exercise 07

Task 1 *The Sun as a neutron star* (2+2+2=6 points)

Assume that the Sun would collapse into a neutron star with a density of approximately $\rho = 5 \times 10^{17}\,\mathrm{kg/m^3}$ at the end of hydrogen burning.

a. What radius would the resulting neutron star have? Neglect all mass losses that the Sun experiences, e.g., through energy production, solar wind, and the explosion at the end of its life cycle.

b. The Sun rotates with a period of 27 days. Its radius is $R_\odot = 6.96 \times 10^8\,\mathrm{m}$. Make the (strongly) simplifying assumption that the mass inside the Sun is uniformly distributed. What frequency would the resulting neutron star rotate at?

c. Would the neutron star be stable at this rotational frequency?

Task 2 *Solar constant* (1+3+3=7 points)

The solar constant measures the radiant power received from the Sun per unit area, based on a receiving surface perpendicular to the incoming radiation at the “upper edge” of the atmosphere. Its value is $1368\,\mathrm{W/m^2}$.

a. What average radiant power is available per square meter of the Earth’s surface?

b. Calculate the mass loss that the Sun experiences per second due to energy production from the solar constant.

c. Estimate the solar neutrino flux generated in the *pp* cycle at the Earth’s surface in units of $\mathrm{cm^{-2}\,s^{-1}}$ when the Sun is at zenith, based on the solar constant. Assume that neutrinos carry away only a negligible portion of the radiated energy. Justify why this is a good approximation. Compare with the value given for the *pp* neutrino flux in Lecture 14.

Task 3 *Apparent magnitude* (3+3=6 points)

The apparent magnitude m is defined as

$$m = -2.5 \cdot \log_{10} \frac{S}{S_0},$$

where $S_0 = 2.518 \times 10^{-8}\,\mathrm{W/m^2}$ is a reference radiant flux. Calculate the apparent magnitude

a. of the Sun,

b. of a star which has the same luminosity as Vega ($d_{\mathrm{Wega}} = 25\,\mathrm{Lj}$), but which is located in the Andromeda galaxy ($d_{\mathrm{Andr}} = 0.78\,\mathrm{Mpc}$).

Task 4 *GZK cutoff* (6 points)

The range of cosmic-ray protons at the highest energies is limited by photoproduction of pions through the reactions

$$p + \gamma \to \Delta^+ \to p + \pi^0 \quad \text{and}$$
$$p + \gamma \to \Delta^+ \to n + \pi^+,$$

respectively. Calculate the threshold energy in units of eV of the protons for this reaction with a photon from the cosmic background radiation. Assume that the photon has an energy corresponding to the maximum of the black body spectrum at a temperature of $T = 2.7\,\mathrm{K}$.