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**Problems set # 9** **Physics 131** December 4, 2018

**1.** Consider a source which emits energy at a rate of $L$ units per second (the type of source, and the units of $L$ are actually irrelevant for this discussion). This situation is shown in the diagram of Fig. 1. Consider a sphere centered on the source, and surrounding it at a radius $r$. If we assume the energy flows out isotropically (this means the flux is the same in all directions) from the source, then the energy received at any point on the sphere should be the same. It is easy to calculate the flux on the sphere, which is the energy as it passes through the sphere (energy/ unit area). It is just the total energy divided by the surface of the sphere. Now, extend this idea to spheres at different radii: the surface area of each sphere increases as $r^2$, so the flux of the energy (per unit area) must reduce as $1/r^2$. This is known as the inverse square law. Approximately $1.6 \times 10^{38}$ neutrinos are produced by the *pp* chain in the Sun every second. Using the inverse square law calculate the number of neutrinos from the Sun that are passing through your brain every second. Imagine your brain as a circle with a diameter of 15 cm.

**2.** Consider a $2M_\odot$ neutron star. The mass of a neutron is $1.67 \times 10^{-24}$ g, and $M_\odot = 2 \times 10^{33}$ g. *(i)* How many neutrons are in this neutron star? *(ii)* Assuming the energy released during core bounce and supernova phase of this neutron star was $3.037 \times 10^{-16}$ Btu per neutron, calculate the total energy output of the supernova in joules. *(iii)* Show that the total energy output of the supernova delivered over the course of a few seconds may be as much as the total output of our Sun during its 10 billion year lifetime. Note that 1 Btu $= 1,055$ J.

**3.** The Schwarzschild radius is the radius of a sphere such that, if all the mass of an object were to be compressed within that sphere, the escape velocity from the surface of the sphere would equal the speed of light. If a stellar remnant were to collapse to or below this radius, light could not escape and the object is no longer directly visible outside, thereby forming a black hole. Estimate the size of the supermassive black hole candidate at the center of our Galaxy. The black hole mass has been estimated to be $4 \times 10^6 M_\odot$.

**4.** Compare how much $^{235}$U is required to fission and how much gasoline is required to burn in order to boil a bathtub (which is approximately 250 liters of water). Consider the initial temperature of the water at 15°C. [*Hint:* In 1 gram of $^{235}$U there are $2.6 \times 10^{21}$ atoms.]

**5.** The nucleus of $^8$Be, which consists of 4 protons and 4 neutrons, is very unstable and spontaneously breaks into two alpha particles (helium nuclei, each consisting of 2 protons and 2 neutrons). *(i)* What is the force between the two alpha particles when they are $5.00 \times 10^{-15}$ m apart, and *(ii)* what will be the magnitude of the acceleration of the alpha particles due to this force? [*Hint*: the mass of an alpha particle is $4.0026u$.]

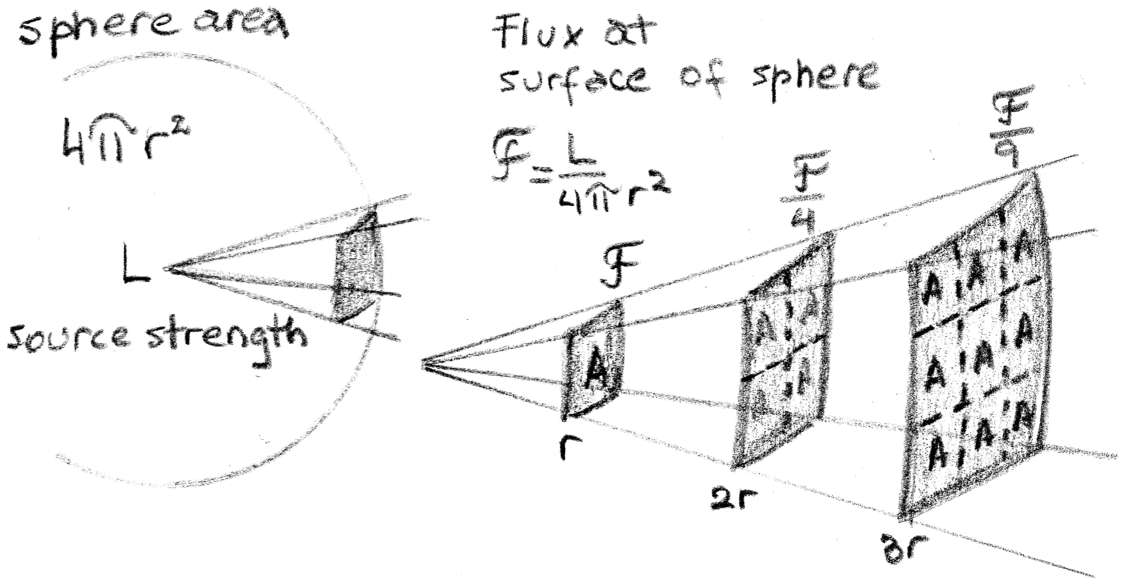


Figure 1: Inverse square law. The energy twice as far from the source is spread over four times the area, hence one-fourth the flux.