IAAC
2020

International Astronomy and Astrophysics Competition

Qualification Round 2020

Answer Sheet

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Problem A : The Solar System (5 Points)

Fill in the blank spaces with the correct information:

The Sun is in the center of Solar System and is composed mainly of the elements (1) and (2). The distance from the Earth to the Sun is also called (3). Many people dream about building a colony on Mars, but the atmosphere is primarily made of (4). We have discovered the (5) between Mars and Jupiter, which contains millions of small objects. Jupiter has a total of (6) moons: The four largest moons are easily visible with a telescope and (7) is the closest and most active one. Uranus and Neptune are the outermost planets and it takes Neptune (8) years to complete one orbit around the Sun.

(1) Hydrogen	(2) Helium	(3) Astronomical units (au)	(4) Carbon dioxide
(5) Asteroid belt	(6) 79	(7) Io	(8) 164

Problem B : Cosmic Scales (5 Points)

Assume the diameter of the Earth (12,700 km) is scaled down to 1 cm and answer the following:

(a) How large is the Sun (diameter: $1.4 \times 10^6\ km$) on this scale?

$$\frac{12{,}700\ km}{1.4 \times 10^6\ km} = \frac{1\ cm}{x}$$

$$x = \frac{1.4 \times 10^6\ km}{12{,}700\ km} \times 1\ cm = 110.2362205\ cm$$

(b) How far away is the nearest star (distance: 4.24 light-years) on this scale?

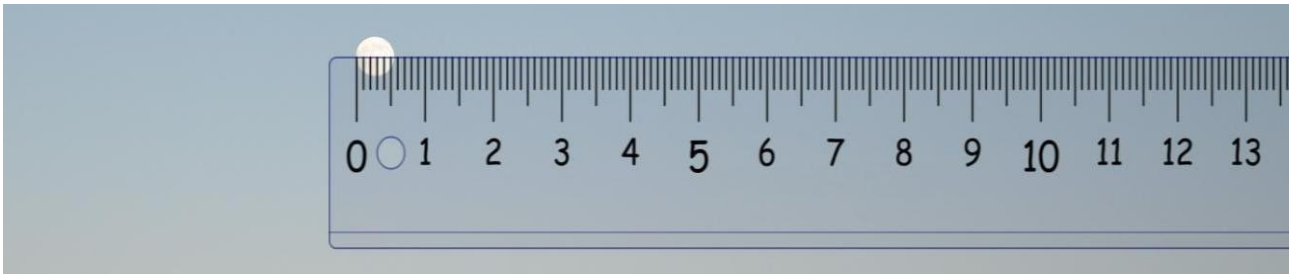
$$1\ \text{light-year} = 2.99792458 \times 10^5\ km/s \times (60{\times}60{\times}24{\times}365.25)\ s = 9.460730473 \times 10^{12}\ km$$

$$\frac{12{,}700\ km}{(4.24 \times 9.460730473 \times 10^{12})\ km} = \frac{1\ cm}{x}$$

$$x = \frac{4.01134972 \times 10^{13}\ km}{12{,}700\ km} \times 1\ cm = 3.158543087 \times 10^9\ cm$$

Problem C : Distance to the Moon (5 Points)

During the daylight, you hold a ruler in a distance of 60 cm away from your eyes, and you find the size of the Moon to be 0.55 cm (try it yourself!). At night, you use a telescope to observe rock formations and craters on the Moon to estimate the diameter of the Moon to be about 3500 km.



Find the distance to the Moon by using only the information from this experiment.

With trigonometry concept, the angular diameter of the Moon which projected through the ruler is:

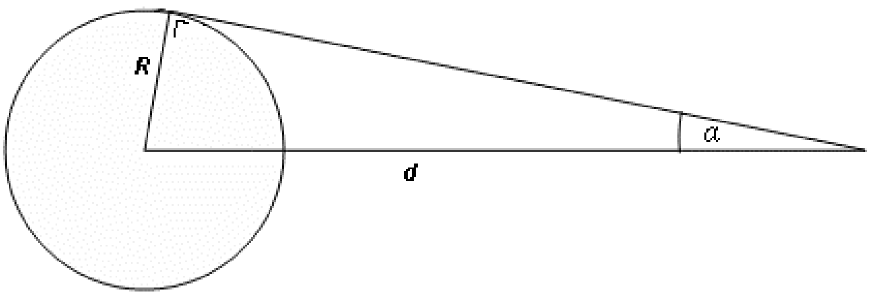
$$\tan\theta = \frac{s_r}{d_r}$$

Where s_r is the size the Moon seen on the ruler and d_r is the distance of the ruler from the eye, then:

$$\theta = \tan^{-1}\left(\frac{s_r}{d_r}\right) = \tan^{-1}\left(\frac{0.55\ cm}{60\ cm}\right) = 0.5251966022°$$

So, the angular radius of the Moon is:

$$\alpha = \frac{\theta}{2} = \frac{0.5251966022°}{2} = 0.2625983011°$$



Based on the illustration above, we can determine the distance of the Moon from its linier radius and the angular radius , ie:

$$\sin\alpha = \frac{R}{d}$$

With R is the radius of the Moon, which is $\frac{3500\ km}{2} = 1750$ km, so:

$$d = \frac{R}{\sin\alpha} = \frac{1750\ km}{\sin 0.2625983011°} = 381{,}830.2128\ km$$

Problem D : Energy of Satellites (5 Points)

A satellite of mass m_S orbits the Earth (with mass m_E and radius R_E) with a velocity v and an altitude h. The gravitational force F_G and the centripetal force F_C are given by:

$$F_G = \mathrm{G}\frac{m_S \cdot m_E}{(R_E + h)^2}, \qquad F_C = \frac{m_S \cdot v^2}{R_E + h}, \qquad G = const.$$

(a) Find an equation for the kinetic energy $E_{kin}(h)$ of a satellite with an altitude h.

The velocity of the satelite is:

$$F_G = F_C$$
$$\mathrm{G}\frac{m_S \cdot m_E}{(R_E + h)^2} = \frac{m_S \cdot v^2}{R_E + h}$$
$$v^2 = G\frac{m_E}{R_E + h}$$

So, the kinetic energy of the satelite is:

$$E_{kin}(h) = \frac{1}{2} \cdot m_S \cdot v^2$$
$$E_{kin}(h) = \frac{1}{2} \cdot m_s \cdot G\frac{m_E}{R_E + h}$$
$$E_{kin}(h) = \frac{G \cdot m_E \cdot m_s}{2(R_E + h)}$$

(b) Based on the kinetic energy, how much liquid hydrogen (energy density: 10^6 J/Litre) is at least needed to bring a small 1 kg satellite in an orbit of 400 km. (Use literature to find m_E, R_E, G.)

$$G = 6.673 \times 10^{-11}\ m^3 kg^{-1} s^{-2}$$
$$m_E = 5.974 \times 10^{24}\ kg$$
$$R_E = 6.378 \times 10^6\ m$$

(Source : Fundamental Astronomy 6th Edition)

$$E_{kin}(h) = \frac{G \cdot m_E \cdot m_s}{2(R_E + h)}$$
$$E_{kin}(h) = \frac{6.673 \times 10^{-11}\ m^3 kg^{-1} s^{-2} \times 5.974 \times 10^{24}\ kg \times 1\ kg}{2(6.378 \times 10^6\ m + 4 \times 10^5\ m)}$$
$$E_{kin}(h) = 2.9407275 \times 10^7\ J$$

So, the liquid hydrogen needed to bring 1 kg satellite is:

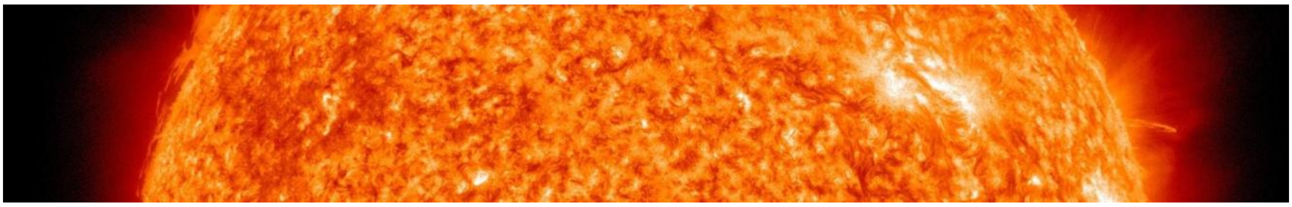
$$E_{kin} = \rho_E \times V$$

Where ρ_E is rhe energy density and V is the volume of liquid hydrogen, then:

$$V = \frac{E_{kin}}{\rho_E} = \frac{2.9407275 \times 10^7\ J}{10^6\ J/Litre} = 29{,}407275\ Litre$$

Problem E : Nuclear Fusion (5 Points)

The light from the Sun is essential for all life on Earth. For a long time, we did not understand where all of this energy is coming from and how the sunlight is generated. Today, we know that the process of nuclear fusion is responsible for the energy production in the Sun and other stars.

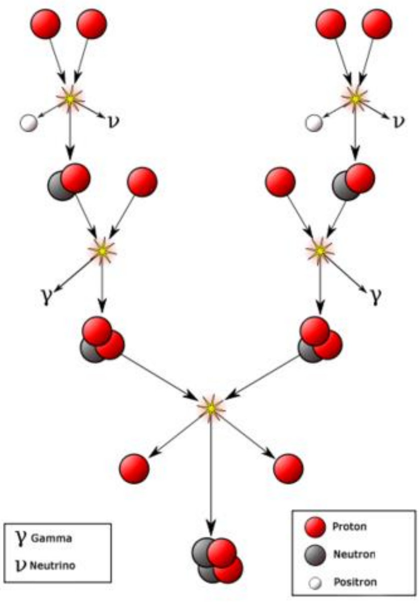


Explain how nuclear fusion in the Sun produces the sunlight we see on Earth.

The energy from the Sun originates from a nuclear fusion process that is occurring inside the core of the Sun. The specific type of fusion that occurs inside of the Sun is known as proton-proton fusion. This process begins with protons (which is simply a lone hydrogen nucleus) and through a series of steps, these protons fuse together and are turned into helium. The transformation from this fusion reaction will result in energy that keep the sun hot. The resulting energy is radiated out from the core of the Sun and moves across the solar system.

The overall process of proton-proton fusion within the Sun can be broken down into several simple steps. A visual representation of this process is shown in figure. The steps are:

1. Two protons within the Sun fuse. Most of the time the pair breaks apart again, but sometimes one of the protons transforms into a neutron via the weak nuclear force. Along with the transformation into a neutron, a positron and neutrino are formed. This resulting proton-neutron pair that forms sometimes is known as deuterium.
2. A third proton collides with the formed deuterium. This collision results in the formation of a helium-3 nucleus and a gamma ray. These gamma rays work their way out from the core of the Sun and are released as sunlight.
3. Two helium-3 nuclei collide, creating a helium-4 nucleus plus two extra neutrons. Technically, a beryllium-6 nuclei forms first but is unstable and thus disintegrates into the helium-4 nucleus.



The final helium-4 atom has less mass than the original 4 protons that came together. Because of this, their combination results in an excess of energy being released in the form of heat and light that exits the Sun, given by the mass-energy equivalence ($E = mc^2$). To get out of the Sun, this energy must travel through many layers to the photosphere before it can actually emerge into space as sunlight and ultimately reach the Earth.