ASTRO 101 – M.M. Montgomery -
montgomery@physics,ucf.edu
Solar Flare Energy Source Homework Problem
LWS Heliophysics Summer School 2013

Target Audience: Upper Division Undergraduate Majors or First Year Grad Students

Concepts Learned: Four fundamental sources in nature and which is/are the source to CMEs and solar flares

Methodology: Calculations

Delivery: Handwritten calculations on one side of a standard 8½"x11" white copy paper, folded lengthwise, with printed name on outside jacket

Materials: standard 8½"x11" white copy paper, pencil, scientific calculator

Assessment: Correct identification from the list of givens, of what is to be found, and of correct assumptions to find the correct answers

Texts and chapters used in this homework assignment:

1. Heliophysics I Plasma Physics of Local Cosmos, Chapter 8

2. Heliophysics II Space Storms and Radiation: Causes and Effects, Chapter 5

Usage: To be assigned after the student sees the CME.ppt and prior to the student performing the "Introduction to the "Introduction to the CME Evolution NASA ENLIL Software" Lab.

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Goal

Your goal in this exercise is to determine if the source to the energy is from gravitational, electrical, nuclear, and/or magnetic field sources.

Given

White light solar flares are observed to have energy $E \sim 10^{32}$ ergs. These flares occur in localized, transient regions through the chromosphere and corona.

For the solar flare, assume the shape is an arch of

area $A = 10^{18}$ cm^2

height $L \sim 10^9$ cm

particle mass column density (from the top of the arch to the location in the Sun's photosphere where the temperature is minimum) $\zeta = 10^{-2}$ g/cm^2

column mass density in the corona $\zeta_{cor} \sim 10^{-6}$ g/cm^2

magnetic field strength $B \sim 10^3$ G in the photosphere near the transient region

For the Sun,

g is acceleration due to gravity

$T_{cor} \sim 10^6$K is the temperature of the corona

$T_{chrom} \sim 10^4$K is the temperature of the chromosphere

For constants,

mass of hydrogen is $m_H \sim 10^{-24}$ g

k is Boltzmann's constant in cgs units

Find

1. Which value of *g* is the best choice for this homework problem? *Hint*: *g*=GM/r2 where G is the universal gravitational constant, M is the mass of the celestial object, and r is the radius of the celestial object.

a. 9.8 m/s^2

b. ~10^4 cm/s^2

c. 32 ft/s^2

d. either 9.8 m/s^2 or 32 ft/s^2

3. ~10^6 m/s^2

Answer: b

Feedback: You should calculate g for the Sun where M is the mass of the Sun and r is the radius of the Sun. See p. 195 of Text #1 for radius and mass of the Sun.

2a. If the gravitational energy in the solar flare is given by

$E_{gravity} = AgL\zeta$

then what is approximate value of $E_{gravity}$ in units of ergs? Show all work.

Answer: $E_{gravity} \sim 10^{29}$ ergs

2b. Can gravitational energy be a source to the typical solar flare? How do you know?

Answer: No, as 10^{29} ergs < 10^{32} ergs.

3a. If the electrical energy in the solar flare is given by the thermal energy

$$E_{electrical,thermal} = \frac{A}{m_H}\left[\zeta_{cor} kT_{cor} + \left(\zeta - \zeta_{cor}\right) kT_{chrom}\right]$$

then what is approximate value of $E_{chemical/thermal}$ in units of ergs? Show all work.

Answer: $E_{chemical/thermal} \sim 10^{28}$ ergs

2b. Can chemical or thermal energy be a source to the typical solar flare? How do you know?

Answer: No, as 10^{28} ergs < 10^{32} ergs.

3. If nuclear fusion energy is given by

$$E_{nuclear} = \eta\psi mc^2$$

where η is the fraction of solar flare's mass that can be used in nuclear fusion; ψ is the efficiency of fusing the η fraction mass into helium from hydrogen, which requires a temperature ~10^7 K; m is the mass of particles in the solar flare; and *c* is the speed of light, can nuclear energy be a viable source? You can assume η=1, all the particles in the solar flare are hydrogen, and ψ=0.007. How do you know? Show all work.

Answer: No, as the temperature in the solar flare is not hot enough for fusion to occur (see Table 8.1 of Text #1 for typical values of the Sun's atmospheres)

4a. If the magnetic energy density (a.k.a., magnetic pressure – see p. 131 of Text #2) is given by

$$\varepsilon_{mag} = \frac{B^2}{8\pi}$$

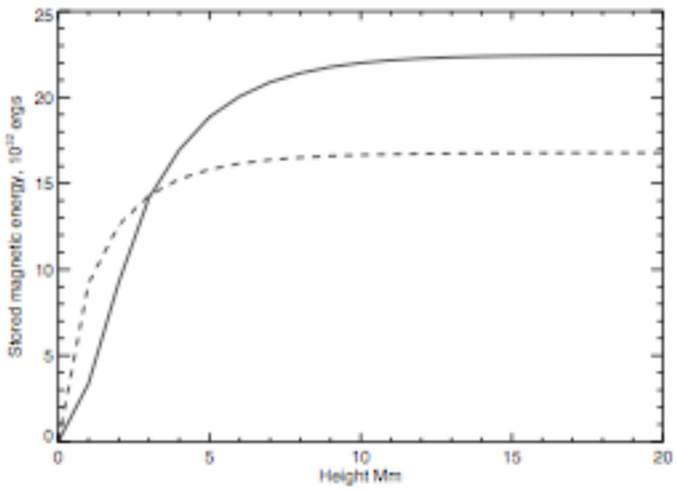
then what is the approximate value of ε_{mag} in units of ergs?

Answer: $\varepsilon_{mag} \sim 10^{32}$ ergs

4b. Can excess energy by increased magnetic field strength be a source to the typical solar flare? How do you know?

Answer: Yes, as the calculated10^{32} ergs is equal to the observed 10^{32} ergs

5a.



For the height of the solar flare given in this problem, what is the value of the stored magnetic field energy in ergs for the non-potential field model? Draw vertical and horizontal lines on the figure above to diagrammatically show your answer.

Answer: For our L, a vertical line is at 10 Mm. The solid line is the non-potential field model (see Figure 5.10 of Text #2) and so the horizontal line yields 22×10^{32} ergs.

5b. Is the point you found on the graph at the ideal location of the stored magnetic energy? How do you know?

Answer: No, the ideal location is at the 50% level, which is around 5 Mm, as discussed in Figure 5.10 of Text #2. The point we found is at the 100% level.

6. Can the typical flare energy discussed in this problem be the energy budget of that from a magnetar? How do you know?

Answer: Refer to p. 150 of Text #2 on magnetars. No, because the Sun will never become a magnetar and thus never have the magnetic field strength of a magnetar.

7. Are any of the assumptions given unreasonable? Support your claims with citations to the texts, providing page and paragraph numbers.

Answer: No, assumptions given are reasonable and supported by information provided in the texts.

8. What is the difference between a solar flare and a coronal mass ejection? Provide page and paragraph numbers from your texts in support of your answer.

Answer: See the top of page 132 in Text #1, for example.

9a. What are the four fundamental forces in nature? Define each

Answer: Gravity, electromagnetism, strong force, weak force

9b. Of these four fundamental forces, which did we consider in this homework thus far?

Answer: Gravity and EM (and maybe the advanced student will make the connections of strong and weak force in nuclear physics)

9c. Of these four fundamental forces, which would not be sources to the solar flare and why?

Answer: Strong and weak forces apply on small scales like the size of the nucleus of an atom or the size of an atom, size scales where they are strongest and size scales not the subject of this homework. Although gravity is a long-range force, it is a weak force as shown in this homework assignment.

What Next?

After completing the homework, try Introduction to CME Evolution NASA ENLIL Software tutorial