

Space Math - III

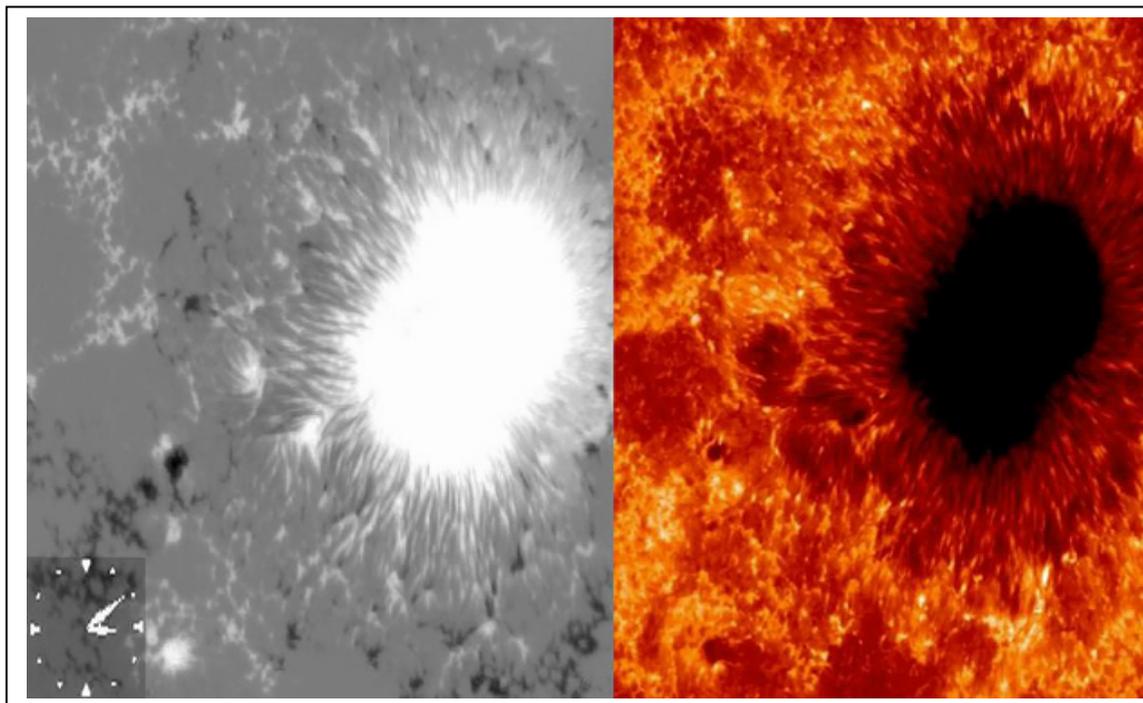
This collection of activities is based on a weekly series of space science problems distributed to thousands of teachers during 2006-2007 school year. They were intended as extra-credit problems for students looking for additional challenges in the math and physical science curriculum in grades 9 through 12. The problems were designed to be authentic glimpses of modern science and engineering issues that come up in designing satellites to work in space, and to provide insight into the basic phenomena of the Sun-Earth system, specifically 'Space Weather'. The problems were designed to be 'one-pagers' with a Teacher's Guide and Answer Key as a second page. This compact form was deemed very popular by participating teachers.

This booklet was created by the NASA, Hinode satellite program's Education and Public Outreach Project.

Writers and Reviewers:

Dr. Sten Odenwald (NASA - Hinode)

Ms. Christine James (Student, B-CC High School, Maryland)



The pictures show sunspot magnetic fields imaged by the Hinode satellite in November, 2006.

For more weekly classroom activities about the Sun-Earth system visit the NASA website,
<http://spacemath.gsfc.nasa.gov>
Add your email address to our mailing list by contacting Dr. Sten Odenwald at
odenwald@mail630.gsfc.nasa.gov

Table of Contents

Acknowledgments	i
Table of Contents.....	ii
Alignment with Standards	iii
Teacher Notes.....	iv
An Introduction to Space Radiation.....	0
Unit Conversion Exercises.....	1
Radiation Background and Lifestyles.....	2
A Perspective on Radiation Dosages.....	3
Having a Hot Time on Mars!	4
Calculating Total Radiation Dosages at Mars.....	5
Single Event Upsets in Aircraft Avionics.....	6
The Deadly Van Allen Belts?	7
Systems of Equations in Space Science.....	8
Monster Functions in Space Science.....	9
Parametric Functions and Substitution.....	10
Radon Gas in the Basement.....	11
Some Puzzling Thoughts about Space Radiation.....	12
Moving Magnetic Fields near Sunspots.....	13
Correcting Bad Data using Parity Bits.....	14
Data Corruption by High-Energy Particles.....	15
The Pressure of a Solar Storm.....	16
Are U Nuts?	17
Lunar Meteorite Impact Risk.....	18
Beyond the Blue Horizon.....	19
Measuring the Speed of a Solar Tsunami.....	20
Do Fast CMEs Produce Intense SPEs?	21
Atmospheric Shielding from Radiation Part I.....	22
Atmospheric Shielding from Radiation Part II.....	23
Atmospheric Shielding from Radiation Part III.....	24
Introduction to Radiation Shielding.....	25
Astronomy as a Career.....	26
Solar Storms; Odds, Fractions and Percentages.....	27
A Study of Astronaut Radiation Dosages.....	28
Hinode Satellite Power.....	29
Hinode - A Closeup of a Sunspot	30
Compound Interest	31
Solar Flare Reconstruction	32
A Lunar Transit of the Sun from Space	33
The Hinode Satellite Views the Sun.....	34
The Sunspot Cycle - Endings and beginnings.....	35
Super-fast Solar Flares.....	36
A Note from the Author.....	37
Useful web links for additional resources.....	39

Teacher Notes. The order of the problems in this book reflects the order in which they were presented as Weekly Problems during the school year and do not represent a logical sequence of science study. Below are the general topic areas that are covered, and a suggested sequence of presentation by level of math difficulty if they are used as part of a course of study.

Radiation Effects on Humans and Technology

An Introduction to Space Radiation	0
Unit Conversion Exercises	1
Correcting Bad Data using Parity Bits	14
Radiation Background and Lifestyles	2
A Perspective on Radiation Dosages	3
Radon Gas in the Basement	11
Some Puzzling Thoughts about Space Radiation	12
Data Corruption by High-Energy Particles	15
Having a Hot Time on Mars!	4
Calculating Total Radiation Dosages at Mars	5
Single Event Upsets in Aircraft Avionics	6
The Deadly Van Allen Belts?	7
A Study of Astronaut Radiation Dosages	28
Introduction to Radiation Shielding	25
Atmospheric Shielding from Radiation Part I	22
Atmospheric Shielding from Radiation Part II	23
Atmospheric Shielding from Radiation Part III	24

Solar Science

Solar Storms; Odds, Fractions and Percentages	27
Do Fast CMEs Produce Intense SPEs?	21
Hinode - A Closeup of a Sunspot	30
The Hinode Satellite Views the Sun	34
Hinode Satellite Power	29
Moving Magnetic Fields near Sunspots	13
Super-fast Solar Flares	36
Measuring the Speed of a Solar Tsunami	20
A Lunar Transit of the Sun from Space	33
The Sunspot Cycle - Endings and beginnings	35
Solar Flare Reconstruction	32
The Pressure of a Solar Storm	16

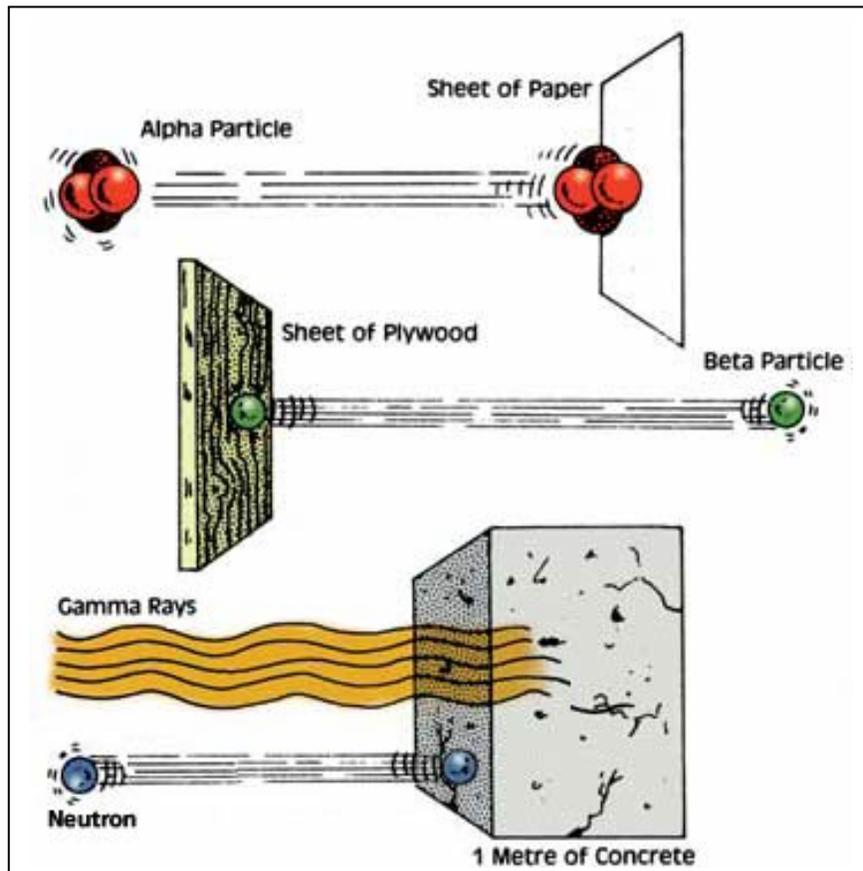
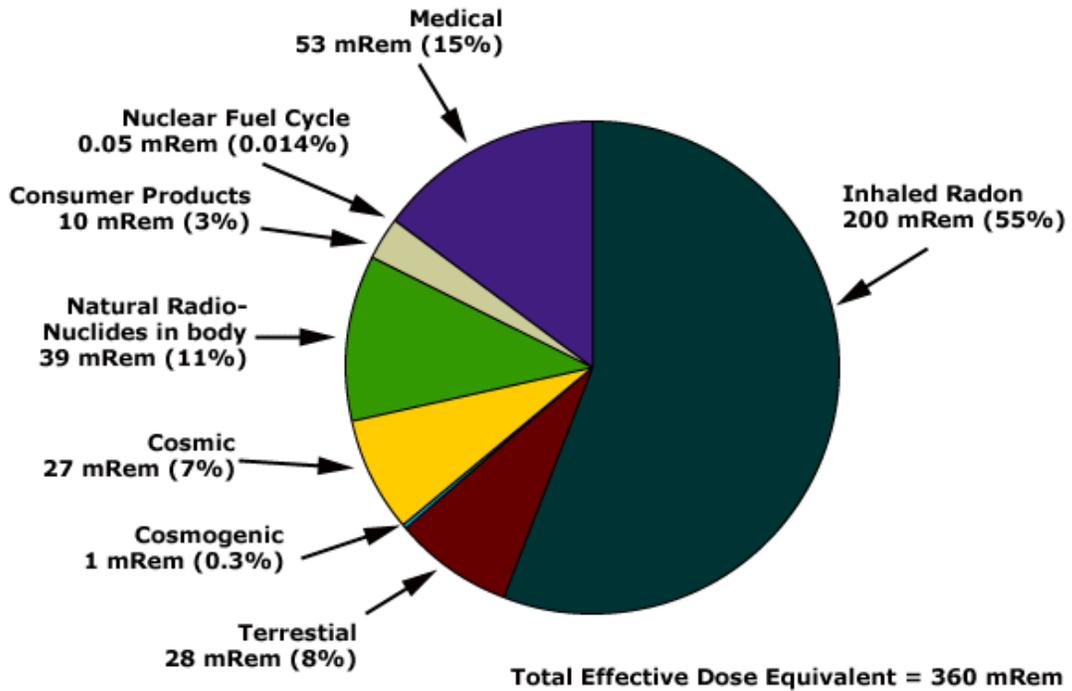
Miscellaneous Math Topics

Are U Nuts?	17
Lunar Meteorite Impact Risk	18
Compound Interest	31
Astronomy as a Career	26
Systems of Equations in Space Science	8
Monster Functions in Space Science	9
Parametric Functions and Substitution	10
Beyond the Blue Horizon	19

Cover Credits: Astronaut White (NASA/Gemini); Mars solar wind (NASA/JPL/ Mars Global Surveyor); International Space Station (NASA/ISS)

Inside Figure Credits: 1) Radiation Pie chart (Lawrence Radiation Lab); 3) Astronaut White (NASA/Gemini); 4) Mars radiation (NASA/Mars Orbiter); 6) Altair UAV (NASA/Dreyden); 7) Van Allen belts (WWW unattributed) Radiation dosages (NASA/CRRES); 8) solar images (NASA/SOHO) Satellite (Boeing); 9) Alien monster (WWW unattributed); 10) Aurora photo (Dick Hutchinson); 11) Radon Map (EPA); 13) Sunspot (Hinode); 150 Solar images (NASA/ESA/SOHO); 16) Magnetosphere model (University of Michigan/SPARC); 17) Squirrel (www unattributed); 18) Lunar impacts (NASA); 19) Mars (NASA); 20) Tsunami waves (National Solar Observatory); 21, 27) solar images (NASA/ESA/SOHO); 22, 23, 24) Earth image (NASA / Apollo 17); 29) Hinode spacecraft (Hinode/RAL - B. E. Johnson); 30) Solar surface (NASA/Hinode); 33) mercury transit (NASA/STEREO); 34) solar corona (Hinode)

Sources of Exposure



Different types of radiation can be shielded by different materials

An Introduction to Space Radiation

Believe it or not, you are surrounded by radiation! As you are sitting here reading this article, electromagnetic radiation from sunlight, electric lights, power cables in the walls, and the local radio station are coursing through your body. Is it something to worry about? It all depends on how much you absorb, and in what forms.

There are two main types of radiation: electromagnetic radiation, and particle radiation. Both forms carry energy, which means that if you accumulate too much over time, either in the tissues of your body, or in sensitive electronic equipment, they can potentially do damage. A small amount of ultraviolet radiation can give you a nice tan. Too much can increase your risk for skin cancer. A small amount of radio radiation is enough to pick up a distant station on your radio, but too much in a microwave oven will cook you in ten seconds flat! A small amount of particle radiation in, say, the radium dial of a watch, is enough to make it glow in the dark harmlessly, but too much can destroy the DNA in your cells and lead to mutations...even death.

Scientists measure radiation dosages and exposure in terms of units called Rads and Rems (Grays and Seiverts are used in Europe). Rad means 'Radiation Equivalent Dose' and REM means 'Roentgen Equivalent Man'. One Rad is equal to 100 ergs of energy delivered to one gram of matter. The Rem compares the amount of absorbed energy to the amount of tissue damage it produces in a human.

$$\text{Rad} = \text{Rem} \times Q$$

Electromagnetic radiation, such as x-rays and gamma-rays, produce 'one unit' of tissue damage, so for this kind of radiation $Q = 1$, and so $1 \text{ Rad} = 1 \text{ Rem}$. Most low-intensity forms of 'EM' radiation can be shielded by using clothing or skin creams. In high dosages, X-rays and gamma-rays require shielding to reduce their health effects, otherwise they can be lethal, or can even incinerate tissue. There are three different kinds of particle radiation, each produces its own level of tissue damage.

Alpha-particles are given-off by radioactive atoms. They are nuclei containing two protons and two neutrons: essentially helium nuclei. These particles, at high energy, can be very destructive to tissue as they leave tracks of ionization in cytoplasm and other cellular tissues. For these $Q = 15-20$.

Beta-particles are also given off by radioactive atoms. They consist of energetic electrons traveling at high-speed, and require several millimeters of aluminum or other shielding to stop most of them. For these, $Q = 1$.

Neutron particles are produced in nuclear reactions including fission and fusion. Because they carry no charge, they easily penetrate many substances. $Q = 10$.

Because of the differences in Q , different forms of radiation produce different levels of tissue damage. Beyond this, radiation also has different effects depending on how much you absorb over different amounts of time. Let's consider two extreme examples where your entire body is 'irradiated': A small dose over a long time, and a big dose over a short time.

Weak and Long! On the ground, you receive about 0.4 Rem (e.g. 400 milliRem) of natural background radiation and radiation from all forms of medical testing, what you eat, and where you live. Over the course of your lifetime, say 80 years, this adds up to $80 \times 0.4 = 32 \text{ Rem}$ of radiation. By far, the biggest contribution comes from radioactive radon gas in your home, which can amount to as much as 0.1 Rem, which yields a lifetime dose of 8 Rem. Some portion of this radiation exposure invariably contributes to the average cancer risk that each and every one of us experiences.

Medical Diagnostic Radiation:

0.002 Rems	Dental x-ray
0.010 Rems	Diagnostic chest X-ray
0.065 Rems	Pelvis/Hip x-ray
0.150 Rems	Barium enema for colonoscopy
0.300 Rems	Mammogram
0.440 Rems	Bone scan
2 to 10 Rem	CT scan of whole body

Strong and Intense! In cancer therapy, small parts of your body are irradiated to kill cancerous cells. This works because radiation transports energy into cellular tissue where it is absorbed, and cancerous cells are very sensitive to heat. Although patients report nausea and loss of hair, the benefits to destroying cancerous cells far outweighs the collateral effects. Typical dosages are about 200 Rems over a few square centimeters, or even 5,000 Rem over a single tumor area! For whole-body dosages, the effects are far worse!

50 - 100 Rems	No significant illness
100 - 200 Rems	Nausea ,vomiting. 10% fatal in 30 days.
200 - 300 Rems	Vomiting. 35% fatal in 30 days.
300 - 400 Rems	Vomiting, diarrhea. 50% fatal in 30 days.
400 - 500 Rems	Hair loss, fever, hemorrhaging in 3wks.
500 - 600 Rems	Internal bleeding. 60% die in 30 days.
600- 1,000 Rems	Intestinal damage. 100% lethal in 14 days.
5,000 Rems	Delerium, Coma: 100% fatal in 7 days.
8,000 Rems	Coma in seconds. Death in an hour.
10,000 Rems	Instant death.

Would you like to check your annual exposure? Visit the American Nuclear Society webpage and take their test at <http://www.ans.org/pi/resources/dosechart/>

or use the one at the US Environmental Protection Agency <http://www.epa.gov/radiation/students/calculate.html>

or the one at the Livermore National Radiation Laboratory <http://newnet.lanl.gov/main.htm>

Questions to ponder, based on the text.

1- During an accident, a 70 kg person absorbed 1,000 Rem of x-ray radiation.

A) How much energy, in ergs, did the person gain?

B) If 41,600,000 ergs is needed to raise the temperature of 1 gram of water by 1 degree C, how many degrees did the radiation raise the person's body temperature if the human body is mostly water?

2 - Your probability of contracting cancer from the natural background radiation (0.3 Rem/year) depends on your lifetime exposure. From detailed statistics, a sudden 1 Rem increase in dosage causes an 0.08% increase in deaths during your lifetime, but the same dosage spread over a lifetime causes about 1/2 this cancer increase. By comparison, cancer studies show that a typical person has an 20% lifetime mortality rate from all sources of cancer. (see "Radiation and Risk", Ohio State University, <http://www.physics.isu.edu/radinf/risk.htm>).

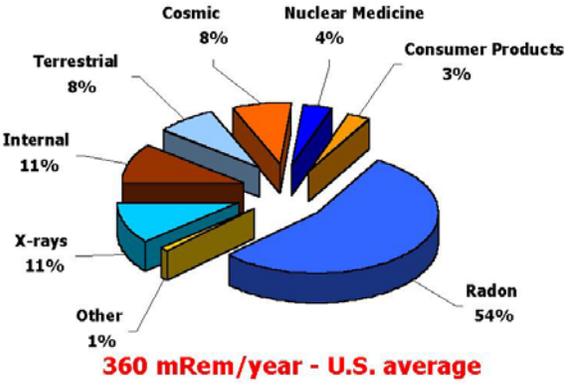
A) Consider 10,000 people exposed to radiation. How many natural cancer deaths would you expect to find in such a sample?

B) How much does the natural background radiation contribute to this cancer death rate?

C) Whenever you take a survey of people, there is a built-in statistical uncertainty in how precisely you can make the measurement, which is found by comparing the sample size to the square-root of the number of samples. In polls, this is referred to as the 'margin of error'. For your answer to Problem 2a, what is the range of people that may die from cancer in this population?

D) Compared to your answer to Problem 2B, do you think you would be able to measure the lifetime deaths from natural background radiation exposure compared to the variation in cancer mortality in this population?

Unit Conversion Exercises



To understand the effect that radiation has on biological systems, a number of different systems for measurement have arisen over the last 50 years. European scientists prefer to use Grays and Seiverts while American scientists still use Rads and Rems!

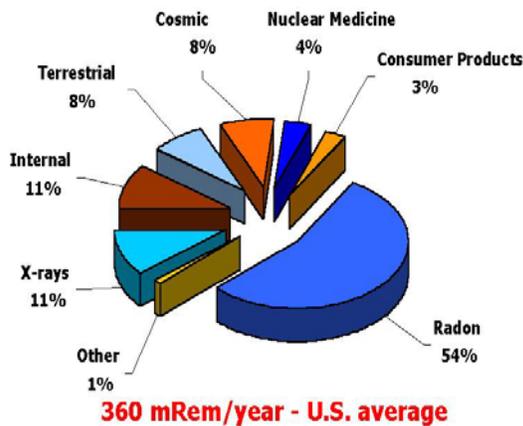
The chart to the left shows your typical radiation dosage on the ground and the factors that contribute to it.

Basic Unit Conversions:	
1 Curie = 37 billion disintegrations/sec	
1 Gray = 100 Rads	0.001 milli
1 Rad = 0.01 Joules/kg	0.000001 micro
1 Seivert = 100 Rems	1 lifetime = 70 years
1 Roentgen = 0.000258 Charges/kg	1 year = 8760 hours
1 microCoulomb/kg = 46 milliRem	1 Coulomb = 6.24 billion billion charges

Convert:

1. 360 milliRem per year tomicroSeiverts per hour
2. 7.8 milliRem per day toRem per year
3. 1 Rad per day toGrays per year
4. 360 milliRem per year toRems per lifetime
5. 3.0 Roentgens to charges per gram
6. 5.6 Seiverts per year tomilliRem per day
7. 537.0 milliGrays per year tomilliRads per hour

Background Radiation and Lifestyles



As we go about our daily lives, we are constantly surrounded by naturally-occurring sources of radiation. The accumulation of this radiation dosage every day throughout our lives leads to our total lifetime dosage. Depending on where we live, and our lifestyles, this lifetime dosage can make us susceptible to various forms of cancers. Generally, the lower your lifetime dose, the lower your risk for cancer.

In the following activity, you will calculate the total lifetime dosages (in Rems) for a person living in several different geographic locations with a variety of lifestyles.

1. Nancy was born in Denver where the cosmic rays (*GCR*) produce 120 milliRem/year and an additional 105 milliRem/year comes from the ground (*Terr.*). After 30 years, she moves to Baton Rouge, Louisiana where *GCR* = 35 milliRem/year and *Terr.* = 40 milliRem/year. At both locations, she buys the same kind of house and she receives 100 milliRem/year from radon gas in the basement. Assuming all other lifestyle sources contribute 50 milliRem/year during her entire life, and that she is now 65 years old, what has been her total radiation dosage to date in Rem?
2. Suppose that Nancy was also a cigarette smoker since she was 16 years old, but that she gave up smoking when she turned 52. How much additional lifetime radiation dosage in Rems did she receive from this habit during the time she lived in Denver and Baton Rouge if her one-pack-a-day habit exposed her to 15 milliRem/year?
3. Suppose that Nancy was also an airline pilot since she was 27 years old. She has been smoking since age 16. She flies 900 hours each year, with 90% of this time spent at cruising altitudes (35,000 feet) where the cosmic radiation dosage is 5 microSeiverts per hour. If 1 Seivert = 100 Rems, how much additional radiation has she received than in your answer to Question 2?
4. Suppose that after 30 years, instead of moving to Baton Rouge, Nancy moved from Denver to Kerala, India where the terrestrial radiation dosage (*Terr.*) is 380 milliRem/year, but gives up smoking. What will be her total dosage by age 65?
5. Instead of being an airline pilot, at age 35 she decides to become a non-smoking astronaut. From Denver, she moved to Baton Rouge for 5 years, and then finds a home in Houston near the NASA Johnson Spaceflight Center, which is the hub of manned spaceflight activities. At this location, *GCR* = 45 milliRem/year and *Terr.* = 30 milliRem/year. At age 39 she becomes the co-pilot for the Space Shuttle Atlantis on a 13-day trip, during which time her radiation dosage is 19 milliRem/day. If she takes three of these trips before age 65, what is her total dosage?

A Perspective on Radiation Dosages



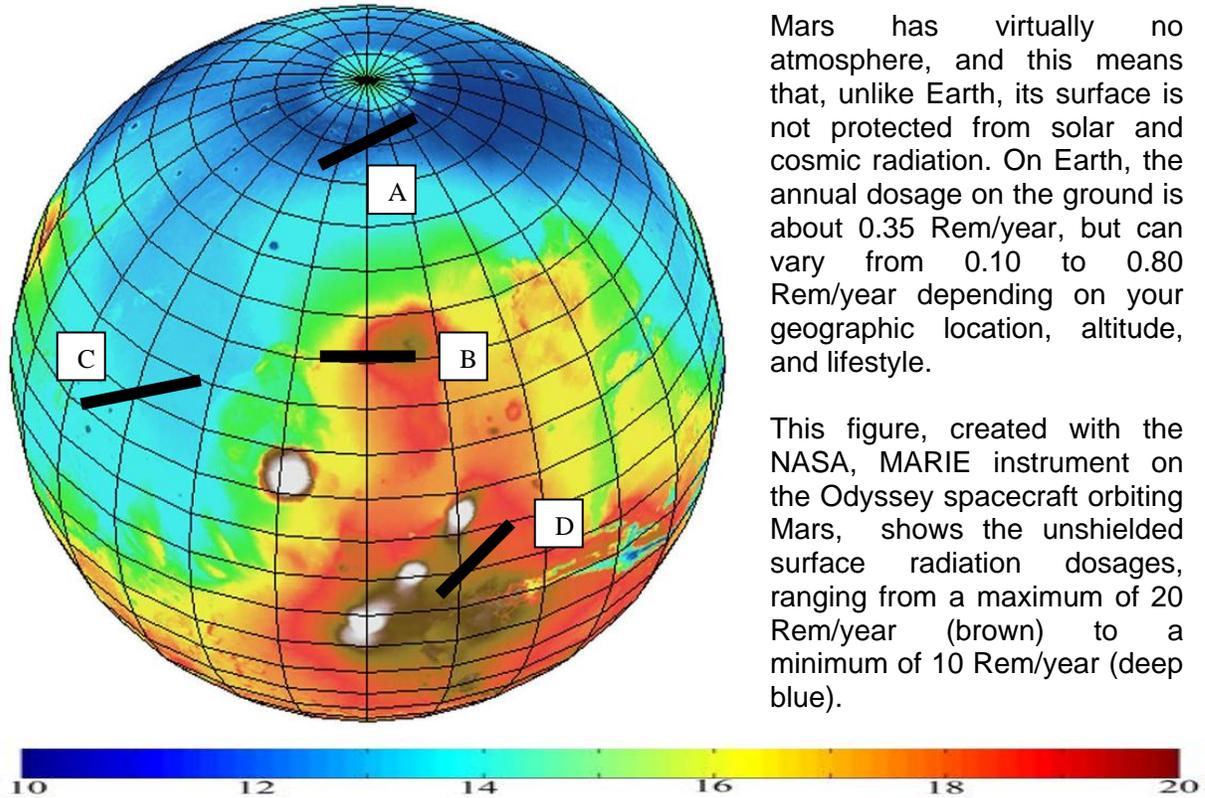
Space travel is understandably a risky business. One of the most well-studied, and worrisome, hazards is the radiation environment. The sun produces streams of high-energy particles and flares, while the universe itself also rains particles down upon us from distant supernova explosions and other energetic phenomena. But how bad is space travel compared to just staying on Earth?

For the following problems, plot how the radiation environment changes for a person living in Denver, on the Space Station, on the Moon, and on a journey to Mars and back. Calculate the total radiation dosage by computing the area under the respective curves.

1. Nancy was born and raised in Denver where her radiation dosage was 350 milliRems/year. At age 25, she moved to Houston where her dosage was 225 milliRems/year, then moved to South Dakota 10 years later where her dosage was 450 milliRems/year until she retired at age 65. Create a plot showing 'YEAR' on the horizontal axis and 'Dosage' on the vertical axis. Prove that the product of the vertical axis units times the horizontal axis units is the total dose in milliRems. Plot Nancy's annual dosages and calculate her total dosage by age 65.

2. An astronaut travels to the Moon on NASA's Orion Crew Vehicle, and spends two weeks on the lunar surface before returning to Earth. The radiation dosage is 19 milliRem/day in Earth orbit for each of two days. The 1/2 day trip through the van Allen belts is 300 milliRem/day. The journey to the Moon takes two days at 50 milliRem/day. The stay on the lunar surface under shielded conditions is 30 milliRem/day. The astronaut returns to Earth retracing the previous conditions, followed by a 2-day stay at the International Space Station, where the dosage is 1.5 milliRem/hour. Plot her dosage history and calculate the total dosage in Rems.

3. An astronaut journeys to Mars. The radiation dosage is 19 milliRem/day at the International Space Station for each of two days. The 1/2 day trip through the van Allen belts was 300 milliRem/day. The crew spends 225 days traveling to Mars, during which time the dosages are 100 milliRems/day. On Mars, for a planned stay of 540 days, the dosage will be about 50 milliRem/day. This is followed by a similar 225-day return to earth, 1/2-day trip through the van Allen Belts, and a 2-day stay at the Space Station. Plot her dosage history and calculate the dosages.



Mars has virtually no atmosphere, and this means that, unlike Earth, its surface is not protected from solar and cosmic radiation. On Earth, the annual dosage on the ground is about 0.35 Rem/year, but can vary from 0.10 to 0.80 Rem/year depending on your geographic location, altitude, and lifestyle.

This figure, created with the NASA, MARIE instrument on the Odyssey spacecraft orbiting Mars, shows the unshielded surface radiation dosages, ranging from a maximum of 20 Rem/year (brown) to a minimum of 10 Rem/year (deep blue).

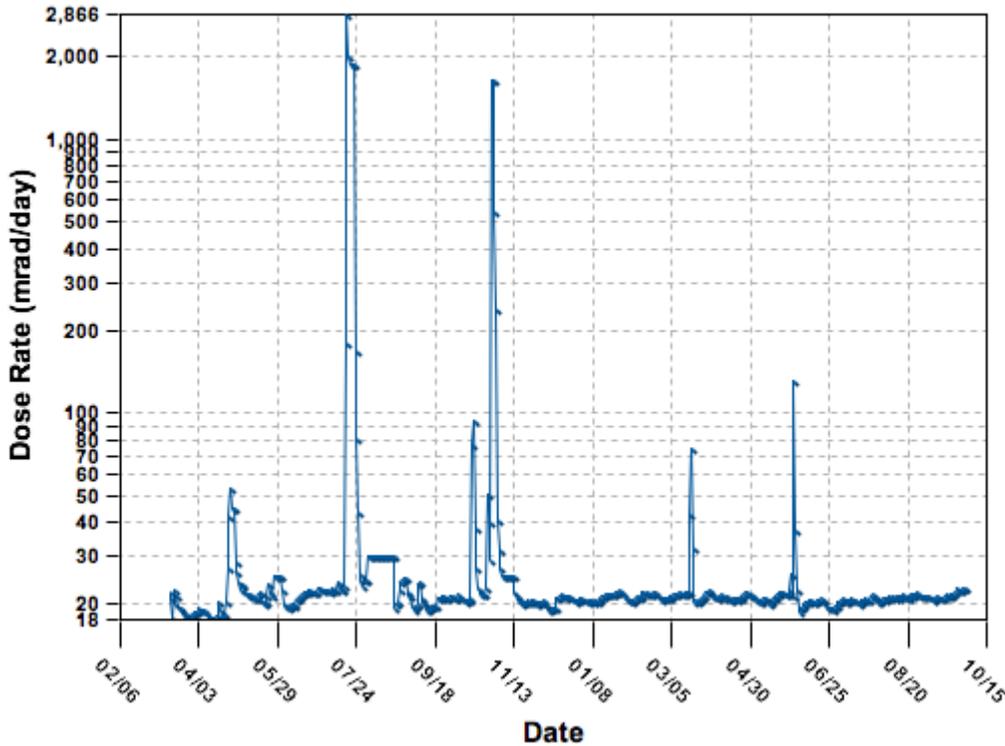
Astronauts landing on Mars will want to minimize their total radiation exposure during the 540 days they will stay on the surface. The Apollo astronauts used spacesuits that provided 0.15 gm/cm^2 of shielding. The Lunar Excursion Module provided 0.2 gm/cm^2 of shielding, and the orbiting Command Module provided 2.4 gm/cm^2 . The reduction in radiation exposure for each of these was about 1/4, 1/10 and 1/50 respectively. Assume that the Mars astronauts used improved spacesuit technology providing a reduction of 1/8, and that the Mars Excursion Vehicle provided a 1/20 radiation reduction.

The line segments on the Mars radiation map represent some imaginary, 1,000 km exploration tracks that ambitious astronauts might attempt with fast-moving rovers, and not a lot of food! Imagine a schedule where they would travel 100 kilometers each day. Suppose they spend 20 hours a day within a shielded rover, and they study their surroundings in spacesuits for 4 hours each day.

- 1) Convert 10 Rem/year into milliRem/day.
- 2) What is the astronaut's radiation dosage per day in a region (brown) where the ambient background produces 20 Rem/year?
- 3) For each of the tracks on the map, plot a dosage history timeline for the 10 days of each journey. From the scaling relationship defined for one day in Problem 3, calculate the approximate total dosage to an astronaut in milliRems (mReMs), given the exposure times and shielding information provided.
- 4) Which track has the highest total dosage in milliReMs? The least total dosage? What is the annual dosage that is equivalent to these 20-day trips? How do these compare with the 350 milliReMs they would receive if they remained on Earth?

Calculating Total Radiation Dosages at Mars

MARIE Daily Average Dose Rates: 03/13/2002 - 09/30/2003



The NASA, Mars Radiation Environment Experiment (MARIE) measured the daily radiation dosages from a satellite orbiting Mars between March 13, 2002 and September 30, 2003 as shown in the figure above. The dose rate is given in units of milliRads per day. (1 Rad = 2 Rems for cosmic radiation.) The six tall 'spikes' are Solar Proton Events (SPEs) which are related to solar flares, while the rest of the plotted data (the wiggly line!) is the dosage caused by galactic cosmic rays (GCRs).

1. By finding the approximate area under the plotted data, calculate the total radiation dosage in Rems for the GCRs during the observation period between 4/03/2002 and 8/20/2003.
2. Assuming that each SPE event lasted 3 days, and that its plotted profile is a simple rectangle, calculate the total radiation dosage in Rems for the SPEs during the observation period.
3. What would be the total radiation dosage for an unshielded astronaut orbiting Mars under these conditions?
4. Are SPEs more important than GCRs as a source of radiation? Explain why or why not in terms of estimation uncertainties that were used.

Single Event Upsets in Aircraft Avionics

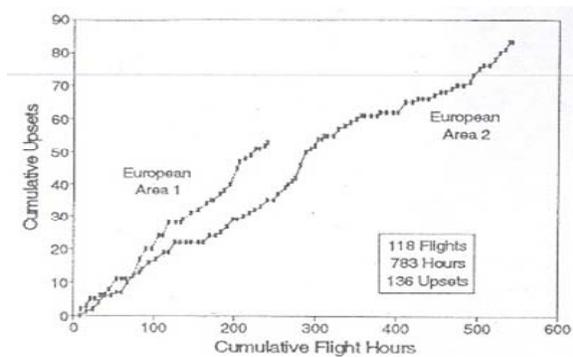
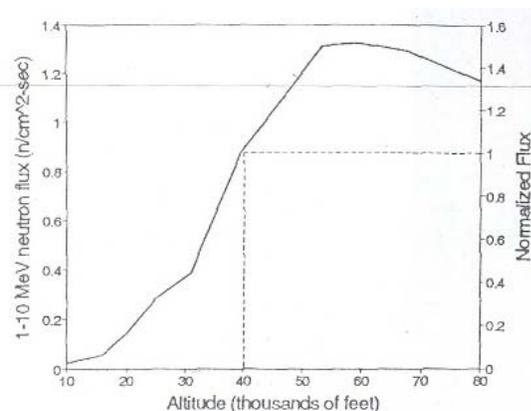


In 2001, the NASA Altair, Unmanned Air Vehicle (UAV) flew its first flight at an altitude of 100,000 feet. Designed by NASA-Dryden engineers and scientists, it is designed to fly for up to 48 hours to complete a variety of science research studies of Earth. For more details about this Dryden program, visit

<http://www.nasa.gov/centers/dryden/news/FactSheets>

Because of the complexity of the computer systems (called **avionics**) onboard, and the very high altitudes being flown, special attention had to be paid to cosmic ray showers. These particles, mostly neutrons, pass through the walls of the aircraft and can affect computer circuitry. For unmanned aircraft, the slightest computer glitch can spell the end of an \$8 million aircraft. This exercise explores some of the issues behind computer glitches at aircraft altitudes.

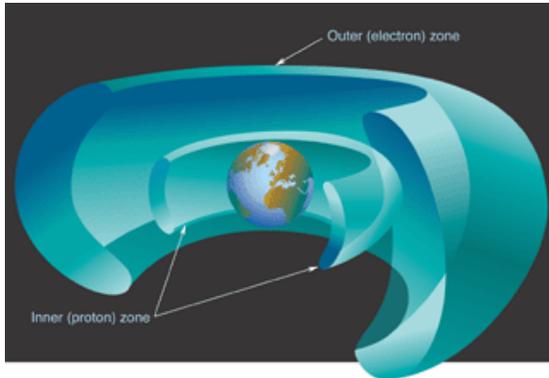
Between the high-radiation environment of space, and the comparative safety of the ground, lies the atmosphere. Most human activity in the military and commercial flight industry takes place between ground-level and 100,000 feet. As cosmic rays collide with atmospheric atoms, they liberate showers of particles deep into the lower atmosphere. The most penetrating of these are the charge-free neutrons. The two figures below show the neutron flux versus altitude, and data taken from aircraft flying at 29,000 feet. The data were taken from a research paper by Taber and Normand (1993), and published in the *IEEE Transactions on Nuclear Science*, vol. 40, No. 2, pp 120.



The left-hand curve gives the number of neutrons that pass through each square centimeter of surface every second (the neutron flux). The right-hand plot gives the cumulative number of memory upsets at an altitude of 30,000 feet after a given number of hours in the air.

1. What is the neutron flux at 30,000 feet? At 60,000 feet?
2. How many memory upsets were registered after 400 hours of flight?
3. If the aircraft carried 1560 memory modules (called SRAMS), each with 64,000 bytes of memory, how many bytes of memory were carried? How many binary 'bits' of memory were carried? (1 byte = 8 bits)
4. If each upset involved one bit having the wrong data value due to a neutron impact, how many bit upsets were registered per day?
5. If the area of each memory unit is $7.5 \times 10^{-9} \text{ cm}^2$, what is the total area of all the memory modules?
6. How many neutrons passed through this area in one second?
7. During the 400 hours of flight, how many neutrons passed through the memory modules?
8. What is the probability that one neutron will cause an upset?
9. How long do you have to wait for an upset to occur at 30,000 feet? At 60,000 feet? At 100,000 feet?

The Deadly Van Allen Belts?

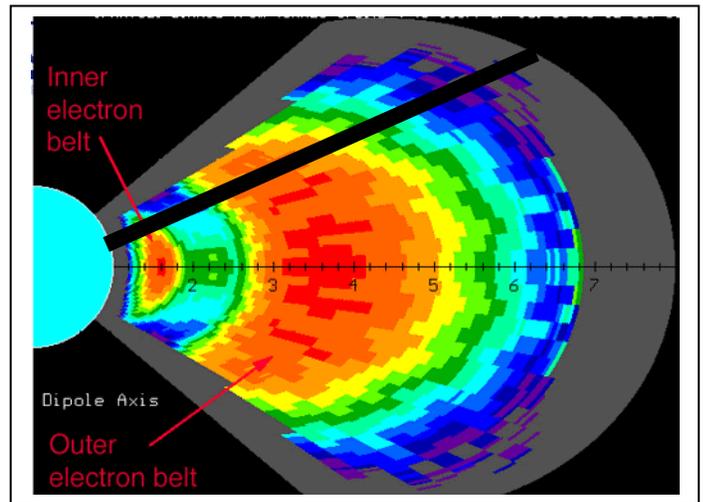


In 1958, Dr. James Van Allen discovered a collection of high-energy particle clouds within 40,000 km of Earth. Arranged like two nested donuts, the inner belt is mainly energetic protons, while the outer belts contain both protons and electrons. These belts have long been known as 'bad news' for satellites and astronauts, with potentially deadly consequences if you spend too much time within them. The figure below, produced by scientists from the NASA, CRRES satellite, shows the radiation dosages at various locations within the belts.

Blue = 0.0001 Rads/sec Green= 0.001 Rads/sec Yellow= 0.005 Rads/sec Orange= 0.01 Rads/sec and Red= 0.05 Rads/sec.

The numbers along the horizontal axis give the distance from Earth in multiples of the Earth radius (1 Re=6378 km). The Inner van Allen Belt is located at about 1.6 Re. The Outer van Allen Belt is located at about 4.0 Re. At a distance of 2.2 Re, there is a 'gap' region in between these belts. Satellites such as the Global Positioning System (GPS) orbit in this gap region where radiation effects are minimum.

The International Space Station and Space Shuttle, on this scale, orbit very near the edge of the blue 'Earth disk' in the figure, so are well below the Van Allen Belts.

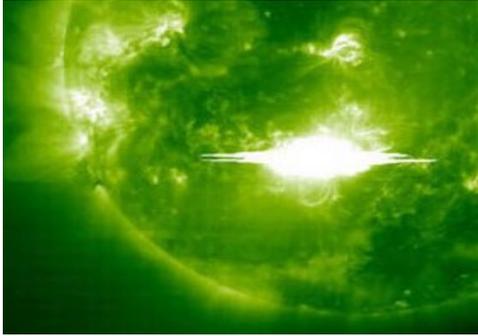


Apollo astronauts, and astronauts in the upcoming visits to the Moon, will have to travel through some of these belt regions because the orbit of the Moon lies along the fastest line-of-travel from Earth. On the scale of the above figure, the distance to the Moon is 60 Re.

1. The speed of the spacecraft will be about 25,000 km/hour. If the spacecraft travels along the indicated path (black bar), how long, in minutes, will it spend in the Blue, Green, Yellow, Orange and Red regions?
2. Given the indicated radiation dosages in Rads/sec for each zone, what will be the dosages that the astronauts receive in each zone?
3. What will be the total radiation dosage in Rads for the transit through the belts?
4. Some people believe that the Apollo moon landings were a hoax because astronauts would have been instantly killed in the radiation belts. According to the US Occupation Safety and Health Agency (OSHA) a lethal radiation dosage is 300 Rads in one hour. What is your answer to the 'moon landing hoax' believers?

Note: According to radiation dosimeters carried by Apollo astronauts, their total dosage for the entire trip to the moon and return was not more than 2 Rads over 6 days

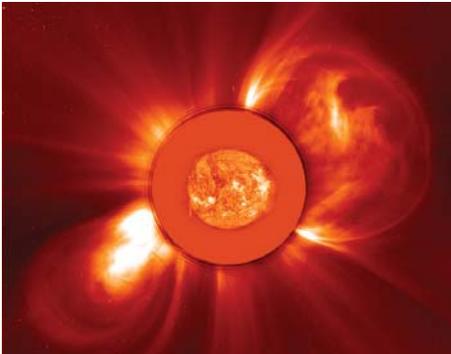
Solving a system of three equations in three unknowns can commonly be found in several space science and astronomy applications.



Solar flares are a frequent phenomenon on the sun, especially during the peaks of solar activity cycles. Over 21,000 can occur during an average solar cycle period of 11 years! In our first problem, you will determine the average intensity of three classes of flares ('C', 'M' and 'X') by using statistical information extracted from three solar activity (sunspot!) cycles.

During February 4 - 6, 2000 the peak month of Cycle 23 solar scientists tallied 37 C-class, 1 M-class and 1 X-class flares, for a total x-ray intensity of 705 mFU (1 mFU = 10^{-6} watts/m²).

During March 4 - 6, 1991 scientists tallied 15 C-class, 14 M-class and 4 X-class flares for a total x-ray intensity of 2775 mFU



During April 1 - 3, 2001 scientists tallied 5 C-class, 9 M-class and 4 X-class flares for a total x-ray intensity of 2475 mFU.

Problem 1: Use the above data to create a system of equations, solve them, and determine the average intensity of flares, to the nearest tenth, in each category (C, M and X) in units of mFU.

Communications satellites use electrical devices called transponders to relay TV and data transmissions from stations to satellite subscribers around the world. There are two basic types: K-band transponders operate at frequencies of 11-15 GHz and C-band transponders operate at 3-7 GHz. Satellites come in a variety of standard models, each having its own power requirements to operate its pointing and positioning systems. The following satellites use the same satellite model:

Satellite 1 : Anik F1
 Total power = 15,000 watts
 Number of K-band transponders = 48
 Number of C-band transponders = 36

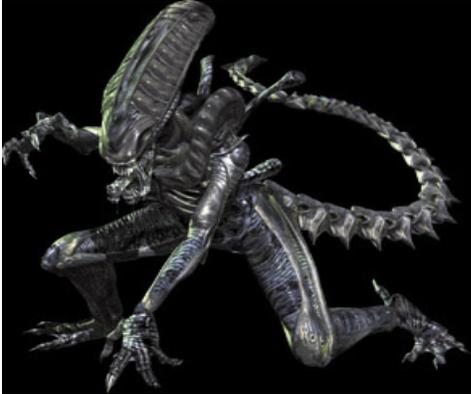
Satellite 2 : Galaxy IIIc
 Total power = 14,900 watts
 Number of K-band transponders = 53
 Number of C-band transponders = 24

Satellite 3 : NSS-8
 Total power = 16,760 watts
 Number of K-band transponders = 56
 Number of C-band transponders = 36

Problem 2: Use the data to determine the average power, to the nearest integer, of a K-band and a C-band transponder, and the satellite operating power, F, in watts.



Monster Functions in Space Science I



Forget about the wimpy formulas you have played with before. Here is a reasonably complex formula that you will have to evaluate, and which will involve all the skills you have previously learned in algebra...and a mastery of scientific notation too!

Be careful, but don't be shy!

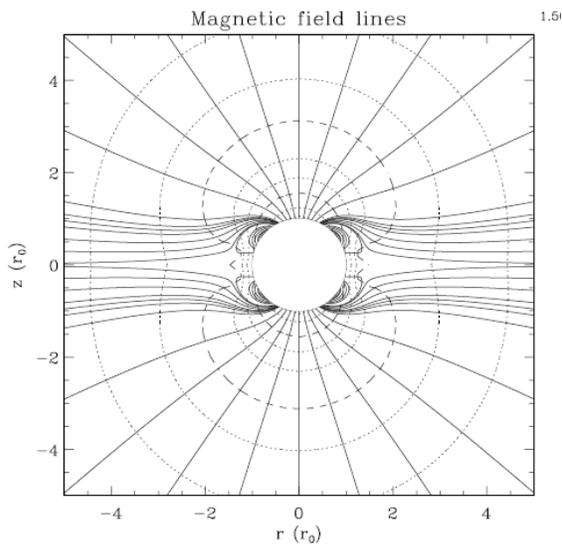
Keep track of your decimal points and exponents!!

And, oh yes....Watch your back!!!

From 'An Analytic Solar Magnetic Field Model' by Banaszekiewicz, Axford and McKenzie (Astronomy and Astrophysics, vol. 337, p. 940-944.

$$\frac{B_\rho}{M} = \frac{3\rho z}{r^5} + \frac{15Q}{8} \frac{\rho z}{r^7} \frac{(4z^2 - 3\rho^2)}{r^2} + \frac{K}{a_1} \frac{\rho}{[(|z| + a_1)^2 + \rho^2]^{3/2}}, \quad (1)$$

$$\frac{B_z}{M} = \frac{2z^2 - \rho^2}{r^5} + \frac{3Q}{8} \frac{(8z^4 + 3\rho^4 - 24\rho^2 z^2)}{r^9} + \frac{K}{a_1} \frac{|z| + a_1}{[(|z| + a_1)^2 + \rho^2]^{3/2}}, \quad (2)$$



These formulas give the two components of the solar magnetic field, in units of Gauss, where $\mathbf{B} = \mathbf{B}_\rho \rho + \mathbf{B}_z z$ where ρ and z are the unit vectors along these two directions.

Problem 1: Evaluate to the nearest tenth B_ρ and B_z for the following conditions appropriate to a distance from the sun equal to Earth's orbit using the following information:

$$M = \rho^2 + z^2 \quad K = 1.0$$

$$Q = 6.03 \times 10^{+17} \text{ kilometers}^3 \quad Q = 1.5$$

$$a_1 = 1.07 \times 10^{+6} \text{ kilometers}$$

$$\text{where } z = -3.48 \times 10^7 \text{ kilometers} \\ \rho = 1.46 \times 10^8 \text{ kilometers.}$$

Problem 2: Find the magnitude of the magnetic field strength using the values of the two computed components from Problem 1.

Problem 3: Explain what effect $|z|$ has on plotting the magnetic field.



Image courtesy Dick Hutchinson

Our sun is an active star that ejects a constant stream of particles into space called the 'solar wind'. From time to time, magnetic activity on its surface also launches fast-moving clouds of plasma into space called 'coronal mass ejections' or CMEs.

When some of these clouds directed at Earth arrive after traveling 93 million miles (150 million km), they cause intense disturbances in Earth's magnetic field. Since the 1800's, these disturbances have been called 'magnetic storms', because instruments on Earth can measure the strength of these disturbances, and they resemble storms in an otherwise very calm magnetic field.

Scientists measure the strength of these magnetic storms in terms of the size of the change they make in the Earth's magnetic field. The strength of Earth's field at the ground is about 0.7 Gauss or 70,000 nanoTeslas. The most intense magnetic storms can change the ground-level field by several percent.

According to research by V. Yurchyshyn, H. Wang and V. Abramenko, which was published in 2004 in the journal Space Weather (vol. 2) the relationship between the magnetic field disturbance, Dst and the Z-component of the interplanetary magnetic field, B_z , is given by:

$$(1) \quad Dst = -2.846 + 6.54 B_z - 0.118 B_z^2 - 0.002 B_z^3$$

where Dst and B_z are measured in nanoTeslas (nT).

In 2004, W. D. Gonzales and his colleagues published a paper in the Journal of Atmospheric and Solar Terrestrial Physics, in which they determined a relation between the speed of a solar coronal mass ejection V, in km/sec, and the strength of Dst in nT according to

$$(2) \quad Dst = 0.00052 \times (0.22 V + 340)^2$$

The relationship between the travel time to Earth from the sun and the speed of the CME was determined from catalogs of CME events by M. J. Owens and P. J. Cargill in research published in 2002 in the Journal of Geophysical Research (vol. 107, p. 1050) in terms of the transit time in days, T, for these coronal mass ejections and their speed, V, in km./sec by

$$(3) \quad T = -0.0042 \times V + 5.14$$

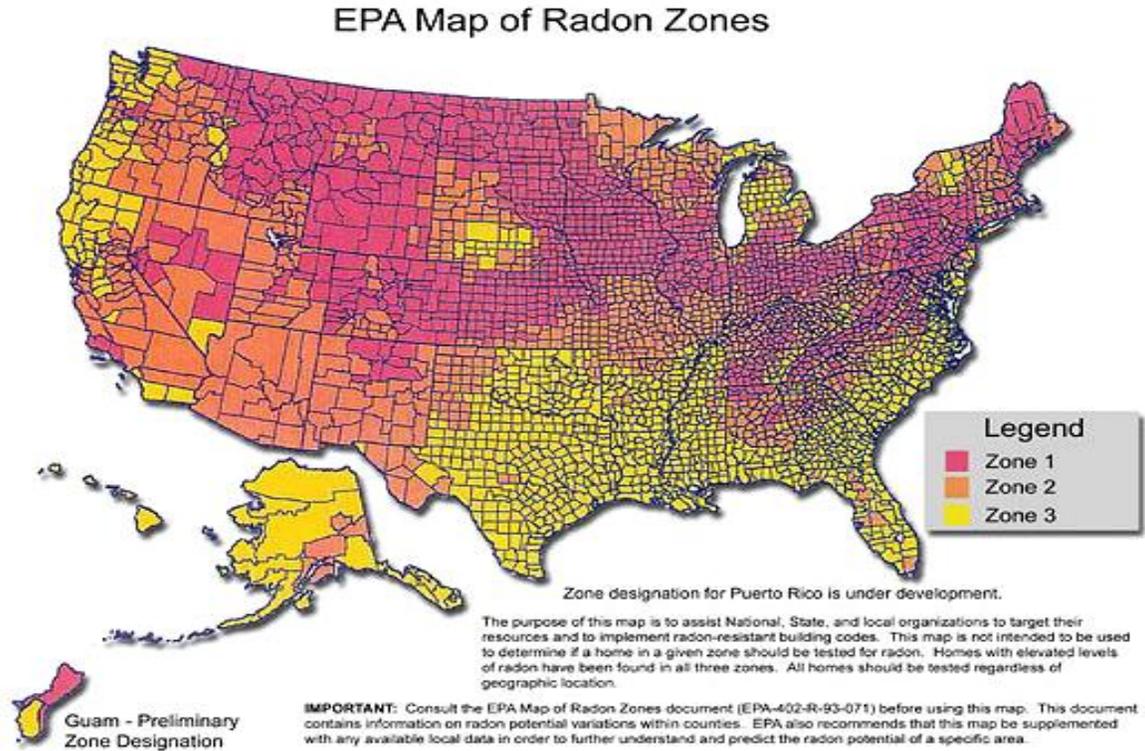
They also found that the maximum interplanetary magnetic field strength of the CME was given by

$$(4) \quad B_T = 0.047 V + 0.644$$

1) From the equation 2 and 3 above, find a function that gives Dst in terms of the transit time of the CME. Write the result in expanded form as a quadratic equation.

2) Assuming that $B_z = B_T / (2)^{1/2}$ use equations 1 and 4 to find a function that gives Dst in terms of V.

3) From equations 2 and 4, find a function that gives Dst in terms of B_T .



Most family rooms (dens) are located in the basements of homes across the country. This is also the place where radon gas can collect over time. When inhaled over time, radon gas adds to your lifetime natural background radiation exposure, and is a significant risk factor for various forms of lung and respiratory cancer. This is why in many states, home buyers must have prospective homes tested before purchase. The typical, annual radiation exposure from all non-radon forms of natural exposure is about 200 milliRem per year.

The above figure shows the four radon zones based on a study by the US Environmental Protection Agency (<http://www.epa.gov/radon/zonemap.html>). By the way, you can also find maps for individual states at this website. The four zones correspond to radiation dosages of Zone 1: 4 picoCuries/liter Zone 2: 3 picoCuries/liter Zone 3: 2 picoCuries/Liter. Note: 4 picoCuries/liter for a full-year exposure is equal to about 3 Rems.

Problem 1: A typical family may only spend 4 hours a day in the basement room. What fraction of a full year does this represent?

Problem 2: In Zone-1, a full years exposure equals 3 Rem. From your answer to Problem 1, what would you predict as the total annual dosage, in milliRems, for a member of this family if they were living in A) Zone-1? B) Zone-2? C) Zone-3?

Problem 3: If a typical lifetime is 80 years, what would be the total lifetime radiation dosage from radon in Rem for the family members in Problem 1 if they lived in A) Zone-1; B) Zone-2; C) Zone-3?

Some Puzzling Thoughts about Space Radiation

We have all heard, since grade school, that 1 _____ affects living systems by causing cell mutations. The particles such as fast-moving ions or 2 _____ strike particular locations in the 3 _____ of a cell, causing the cell to malfunction, or 4 _____ and pass-on a 5 _____ to its progeny. Sometimes the mutations are not beneficial to an organism, or to the evolution of its species. When this happens you can get 6 _____.

Cancer risks are generally related to the total amount of lifetime radiation exposure. The studies of 7 _____ survivors, however, still show that there is much we have to learn about just how radiation delivers its harmful impact. Very large 8 _____ over a short period of time seem not to have quite the deleterious affect that, say, a small dosage delivered steadily over many years does.

The National Academy of Sciences has looked into this issue rather carefully over the years to find a relationship between 9 _____ cancer risks and low-level radiation exposure. What they concluded was that you get up to 100 cancers per 100,000 people for every 1000 10 _____ of additional dosage per year above the natural 11 _____ rate. If a dosage of 1000 millirems extra radiation per year, adds 100 extra deaths per 100,000, then as little as one extra millirem per annum could cause cancer in one person per 12 _____. Although it's just a 13 _____ estimate, if you happen to be that 'one person' you will be understandably 14 _____. No scientific study, by the way, has shown that radiation has such a 15 _____ impact at all levels below 100 millirem, but that's what the 16 _____ application of arithmetic shows.

Government safety regulations now require that people who work with radiation, such as 17 _____, nuclear medicine technologists, or nuclear power plant operators, are given a maximum permissible dose limit of 500 millirems per year above the prevailing 18 _____ background rate. For you and me doing ordinary work in the office, factory or store, the acceptable maximum dose is 1000 milliRems/year above the 350 milliRem you get each year from natural sources. As a comparison, if you lived within 20 miles of the 19 _____ nuclear power 20 _____ at the time of its 21 _____ meltdown, your annual dose would have been about 1500 milliRem/year during the first year, declining slowly as the radioactive 22 _____ in the environment decay

(Excerpted from "The 23rd Cycle", Sten Odenwald, Columbia University Press)

Solve for X in each equation, and select the correct word from the pair of solutions for X, to fill-in the indicated blanks from 1 to 22 in the essay above.

1) $x^2 - 2x - 3 = 0$

2) $x^2 + 4x - 5 = 0$

3) $x^2 - 3x + 2 = 0$

4) $x^2 - x - 12 = 0$

5) $2x^2 - 12x + 10 = 0$

6) $x^2 - 2x - 24 = 0$

7) $x^2 + 5x + 6 = 0$

8) $x^2 - 9 = 0$

9) $2x^2 + 4x - 30 = 0$

10) $3x^2 + 3x - 6 = 0$

11) $x^2 - 6x - 16 = 0$

12) $x^2 - 3x - 88 = 0$

13) $x^2 - 4x - 21 = 0$

14) $x^2 - x - 30 = 0$

15) $x^2 - 9x - 36 = 0$

16) $x^2 - 16x + 63 = 0$

17) $x^2 + 16x + 63 = 0$

18) $x^2 + 14x + 48 = 0$

19) $x^2 + 19x + 90 = 0$

20) $x^2 + 8x - 33 = 0$

21) $x^2 - 100 = 0$

22) $x^2 - 8x = 0$

Word bank - factor list

-11 plant

-10 2005

-9 Chernobyl

-8 million

-7 dentists

-6 natural

-5 neutrons

-4 cancer

-3 dosages

-2 Hiroshima

-1 radiation

0 isotopes

1 milliRems

2 DNA

3 lifetime

4 survive

5 mutation

6 upset

7 statistical

8 background

9 blind

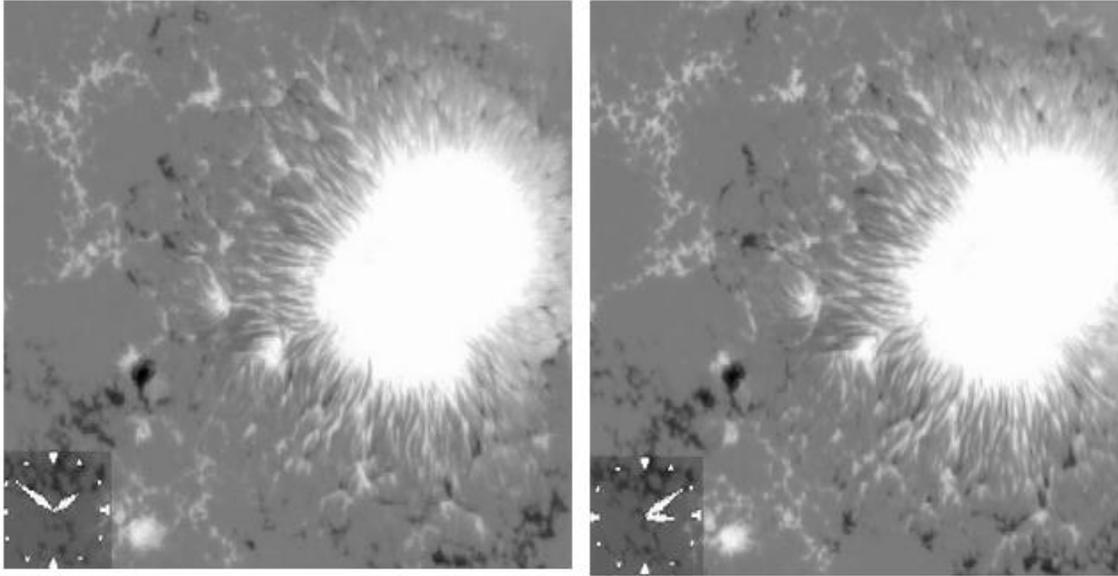
10 1986

11 hundred

12 linear

Moving Magnetic Filaments Near Sunspots

13



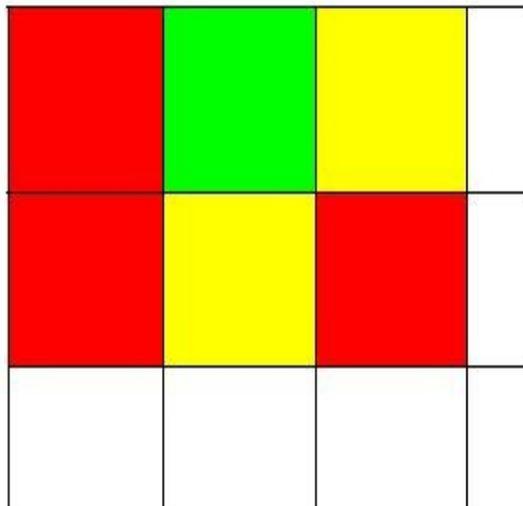
These two images were taken by the Hinode (Solar-B) solar observatory on October 30, 2006. The size of each image is 34,300 km on a side. The clock face shows the time when each image was taken, and represents the face of an ordinary 12-hour clock.

- 1) What is the scale of each image in kilometers per millimeter?
- 2) What is the elapsed time between each image in; A) hours and minutes? B) decimal hours? C) seconds?

Carefully study each image and look for at least 5 features that have changed their location between the two images. (Hint, use the nearest edge of the image as a reference).

- 3) What direction are they moving relative to the sunspot?
- 4) How far, in millimeters have they traveled on the image?
- 5) From your answers to questions 1, 2 and 4, calculate their speed in kilometers per second, and kilometers per hour.
- 6) A fast passenger jet plane travels at 600 miles per hour. The Space Shuttle travels 28,000 miles per hour. If 1.0 kilometer = 0.64 miles, how fast do these two craft travel in kilometers per second?
- 7) Can the Space Shuttle out-race any of the features you identified in the sunspot image?

Correcting Bad Data Using Parity Bits



The first few pixels in a large image

Data is sent as a string of '1's and '0's which are then converted into useful numbers by computer programs. A common application is in digital imaging. Each pixel is represented as a 'data word' and the image is recovered by relating the value of the data word to an intensity or a particular color. In the sample image to the left, red is represented by the data word '10110011', green is represented by '11100101' and yellow by the word '00111000', so the first three pixels would be transmitted as the 'three word' string '101100111110010100111000'. But what if one of those 1-s or 0-s was accidentally reversed? You would get a garbled string and an error in the color used in a particular pixel.

Since the beginning of the Computer Era, engineers have anticipated this problem by adding a 'parity bit' to each data word. The bit is '1' if there are an even number of 1's in the word, and '0' if there is an odd number of 1's. In the data word for red '10110011' the last '1' to the right is the parity bit.

When data is produced in space, it is protected by parity bits, which alert the scientists that a particular data word may have been corrupted by a cosmic ray accidentally altering one of the data bits in the word. For example, Data Word A '11100011' is valid but Data Word B '11110011' is not. There are five '1's but instead of the parity bit being '0' ('11100010'), it is '1' which means Data Word B had one extra '1' added somewhere. One way to recover the good data is to simply re-transmit data words several times and fill-in the bad data words with the good words from one of the other transmissions. For example:

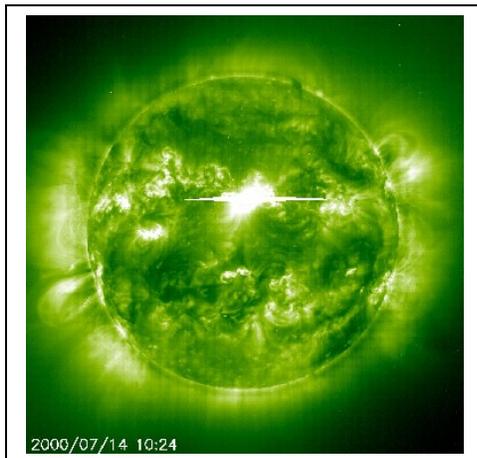
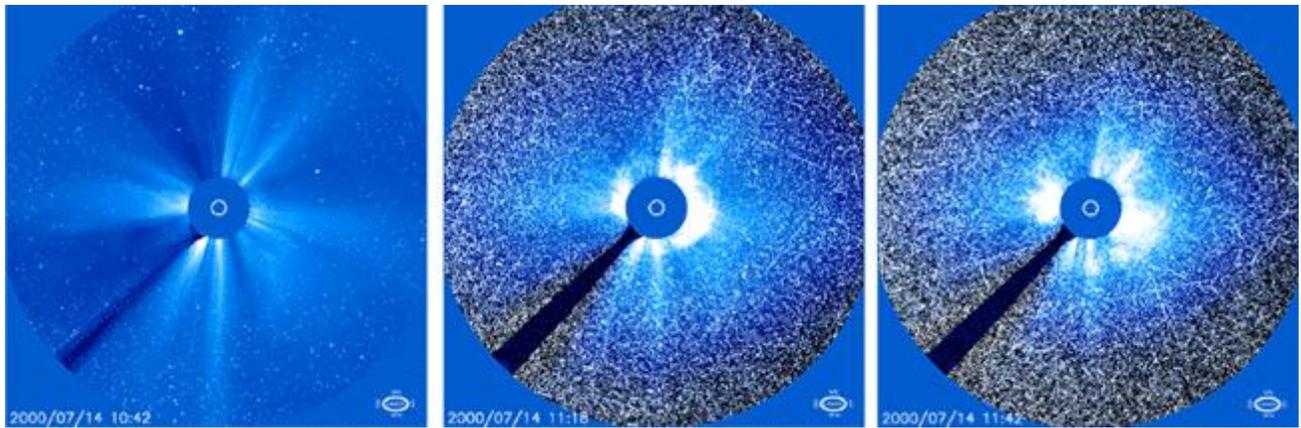
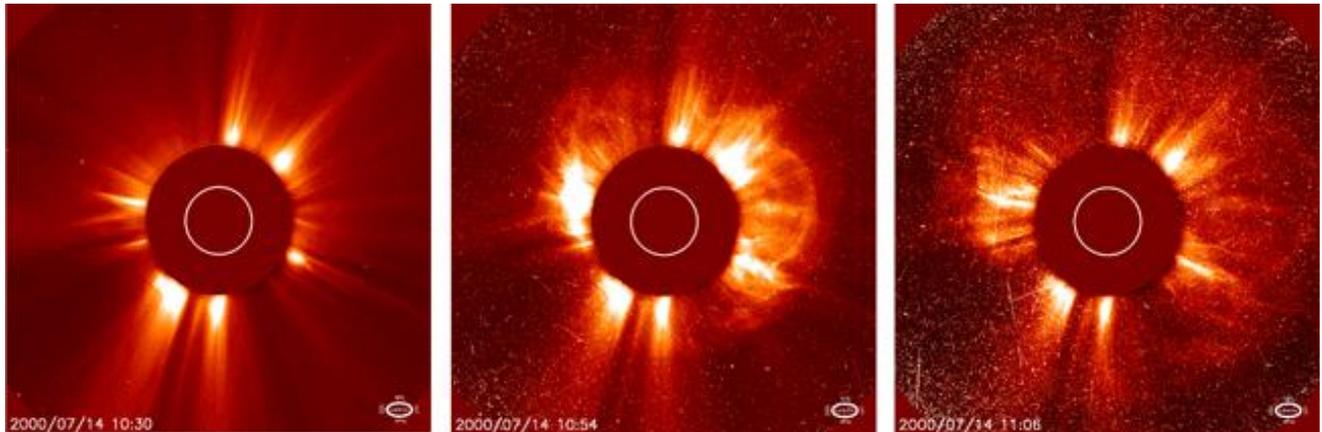
Corrupted data string:	10111100	1011010	10101011	00110011	10111010
Good data string:	10111100	1001010	10101011	10110011	10111010

The second and fourth words have been corrupted, but because the string was re-transmitted twice, we were able to 'flag' the bad word and replace it with a good word with the correct parity bit. Cosmic rays often cause bad data in hundreds of data words in each picture, but because pictures are re-transmitted two or three times, the bad data can be eliminated and a corrected image created.

Problem: Below are two data strings that have been corrupted by cosmic ray glitches. Look through the data (a process called parsing) and use the right-most parity bit to identify all the bad data. Create a valid data string that has been 'de-glitched'.

String 1:	10111010	11110101	10111100	11001011	00101101
	01010000	01111010	10001100	00110111	00100110
	01111000	11001101	10110111	11011010	11100001
	10001010	10001111	01110011	10010011	11001011

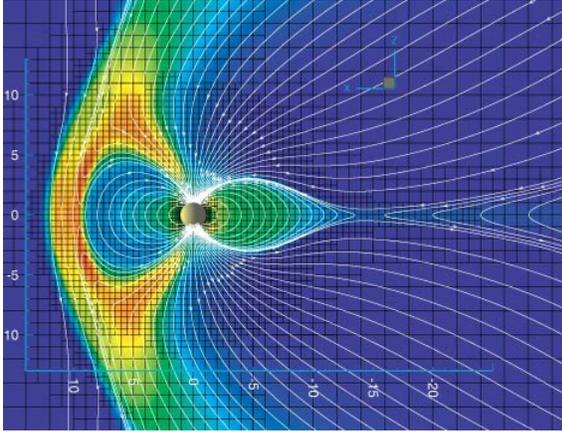
String 2:	10111010	01110101	10111100	11011011	10101101
	01011010	01111010	10001000	10110111	00100110
	11011000	11001101	10110101	11011010	11110001
	10001010	10011111	01110011	10010001	11001011



Solar flares can severely affect sensitive instruments in space and corrupt the data that they produce. On July 14, 2000 the sun produced a powerful X-class flare, which was captured by instruments onboard the Solar and Heliospheric Observatory (SOHO). The EIT imager operating at a wavelength of 195 Angstroms, showed a brilliant flash of light (left image). When these particles arrived at the SOHO satellite some time later, they caused the imaging equipment to develop 'snow' as the individual particles streaked through the sensitive electronic equipment. The above images taken by the SOHO LASCO c2 and c3 imagers show what happened to that instrument when this shower of particles arrived. The date and time information (hr : min) is given in the lower left corner of each image, and give the approximate times of the events.

- Problem 1:** At about what time did the solar flare first erupt on the sun?
- Problem 2:** At about what time did the LASCO imagers begin to show significant signs of the particles having arrived?
- Problem 3:** If the SOHO satellite was located 147 million kilometers from the sun, about what was the speed of the arriving particles?
- Problem 4:** If the speed of light is 300,000 km/sec, what percentage of light-speed were the particles traveling?

The Pressure of a Solar Storm



The ACE satellite measures the density and speed of the solar wind as it approaches Earth, and also measures the strength of its magnetic field. Both the magnetic field, and the kinetic energy of the particles, cause a build-up of pressure acting upon Earth's magnetic field. This forces Earth's magnetic field closer to the planet's surface, and can expose satellites orbiting Earth to the potentially harmful effects of cosmic rays and other high-energy particles. Based on actual data from the ACE satellite, in this problem you will calculate the particle and magnetic pressure and determine the distance from Earth of the pressure equilibrium region of the magnetic field, called the magnetopause. Image (left) courtesy:

<http://www.tecplot.com/showcase/studies/2001/michigan.htm>

Magnetopause Distance:

$$R^6 = \frac{1.8 \times 10^{12}}{N V^2}$$

- V – gas speed in km/sec,
- R – magnetopause distance in Re
- N – gas density in particles/cc

Ram Pressure:

$$Pr = 1.6 \times 10^{-8} N V^2$$

- N - gas density in particles/cc
- V - gas speed in km/sec
- Pr – ram pressure in microErgs/cc

Magnetic Pressure:

$$Pm = 4.0 \times 10^{-6} B^2$$

- B – Cloud's field strength in nanoTeslas (nT)
- Pm – magnetic pressure in microErgs/cc

Date	Flare	N (particle/cc)	V (km/s)	B (nT)	Pr	Pm	Distance (Re)
9-7-2005	X-17	50	2500	50	5.0	0.01	4.2
7-13-2005	X-14	30	2000	20			
1-16-2005	X-2.8	70	3700	70			
10-28-2003	X-17	100	2700	70			
11-4-2003	X-28	80	2300	49	6.8	0.01	4.0
4-21-2002	X-1.5	20	2421	10			
7-23-2002	X-4.8	40	1200	15			
4-6-2001	X-5.6	20	1184	20			
7-14-2000	X-5.7	30	2300	60			
11-24-2000	X-1.8	50	2000	10	3.2	0.0004	4.6
8-24-1998	X-1	15	1500	10			

Note: Density and magnetic field strength are estimates for purposes of this calculation only.

Problem 1: Use the formulae and the values cited in the table to complete the last three columns. A few cases have been computed as examples.

Problem 2: A geosynchronous communications satellite is orbiting at a distance of 6.6 Re (1 Re = 1 Earth radius= 6,378 km). For which storms will the satellite be directly affected by the solar storm particles?

Problem 3: Within each storm event, which pressure is the strongest, ram pressure or magnetic pressure?



Converting from one set of units to another is something that scientists do every day. We have made this easier by adopting metric units wherever possible, and re-defining our standard units of measure so that they are compatible with the new metric units wherever possible.

In the western world, certain older units have been replaced by the modern ones, which are now adopted the world over. (see Wikipedia under 'English Units' for more examples). In this exercise, you will convert from...

Conversion Table:

4 Gallons = 1 Bucket	142.065 cubic cm = 1 Noggin
9 Gallons = 1 Firkin	1.296 grams = 1 Scruple
126 Gallons = 1 Butt	201.168 meters = 1 Furlong
34.07 Liters = 1 Firkin	14 days = 1 Fortnight
0.0685 Slugs = 1 Kilogram	0.2 grams = 1 Carat

- 1) A typical aquarium holds 25 gallons of water. Convert this to A) Firkins; B) Liters, and C) Buckets.
- 2) John weighs 7.2 Slugs, and Mary weighs 53 kilograms. Who weighs the most kilograms?
- 3) The passenger volume of a car is about 5.4 cubic meters. How many Noggins can fit inside the car?
- 4) Sven weighs 105 kilograms and finished a diet of pickled herring, losing 3.8 kilograms. A) How many Scruples did he lose? B) How many Scruples did he start out with?
- 5) The density of water is 1.0 grams/cm^3 . How many Scruples per Noggin is this?
- 6) Evelyn finished the Diamond Man Marathon by walking 400 kilometers in 18 days. What was her average speed in Furlongs per Fortnight?
- 7) A swimming pool holds 50,000 gallons of water. How many Butts were in the pool?
- 8) If a Fathom is 72 inches, and there are 2.5 centimeters per inch, how many kilometers are there in 3.6 Leagues if 1 League = 2640 Fathoms?
- 9) The original Cullinan Diamond was discovered in 1904 and weighs 3,106.75 Carats. A) How many grams is this? B) The polished Cullinan Diamond I (Great Star of Africa) weighs 530.2 Carats and is worth \$386 million. What is the approximate worth of the original Cullinan Diamond? C) What is the going rate for diamonds in terms of dollars per Carat? D) Dollars per gram?

Lunar Meteorite Impact Risks



A December 4, 2006 CNN.Com news story, based on the research by Bill Cooke, head of NASA's Meteoroid Environment Office suggests that one of the largest dangers to lunar explorers will be meteorite impacts. Between November 2005 and November 2006, Dr. Cooke's observations of lunar flashes (see image) found 12 of these events in a single year. The flashes were caused primarily by Leonid Meteors about 3-inches across, impacting with the equivalent energy of 150-300 pounds of TNT.

The diameter of the moon is 3,476 kilometers.

Problem 1: From the formula for the surface of a sphere, what is the area, in square kilometers, of the side of the moon facing Earth?

Problem 2: Although an actual impact only affects the few square meters within its immediate vicinity, we can define an impact zone area as the total area of the surface being struck, by the number of objects striking it. What was the average impact zone area for a single event?

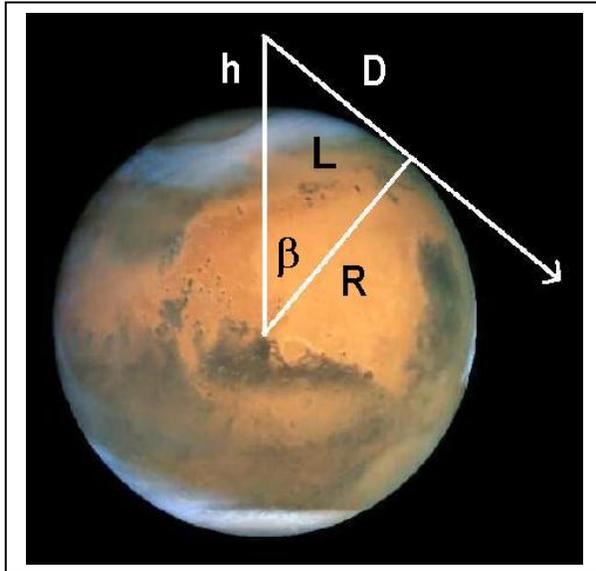
Problem 3: Assuming the area is a square with a side length 'S', A) what is the length of the side of the impact area? B) What is the average distance between the centers of each impact area?

Problem 4: If the impacts happen randomly and uniformly in time, about what would be the time interval between impacts?

Problem 5: From the vantage point of an astronaut standing on the Moon, the horizon is about 3 kilometers away. How long would the lunar colony have to wait before it was likely to see an impact within its horizon area?

Problem 6: The lunar image shows that the impacts are not really random, but seem clustered into three groups. Each group covers an area about 700 kilometers on a side. What is the average impact zone area for four strikes per zone?

Problem 7: If you were an colony located in one of these three zones, what would be your answer to Problem 5?



An important quantity in planetary exploration is the distance to the horizon. This will, naturally, depend on the diameter of the planet (or asteroid!) and the height of the observer above the ground.

Another application of this geometry is in determining the height of a transmission antenna in order to insure proper reception out to a specified distance.

Teachers: Problems 1-4 can be successfully accomplished by algebra students. Problems 5 and 6 require a knowledge of derivatives and can be assigned to calculus students after they have completed Problem 1 and 2.

Problem 1: If the radius of the planet is given by R , and the height above the surface is given by h , use the figure above to derive the formula for the line-of-sight horizon distance, D , to the horizon tangent point.

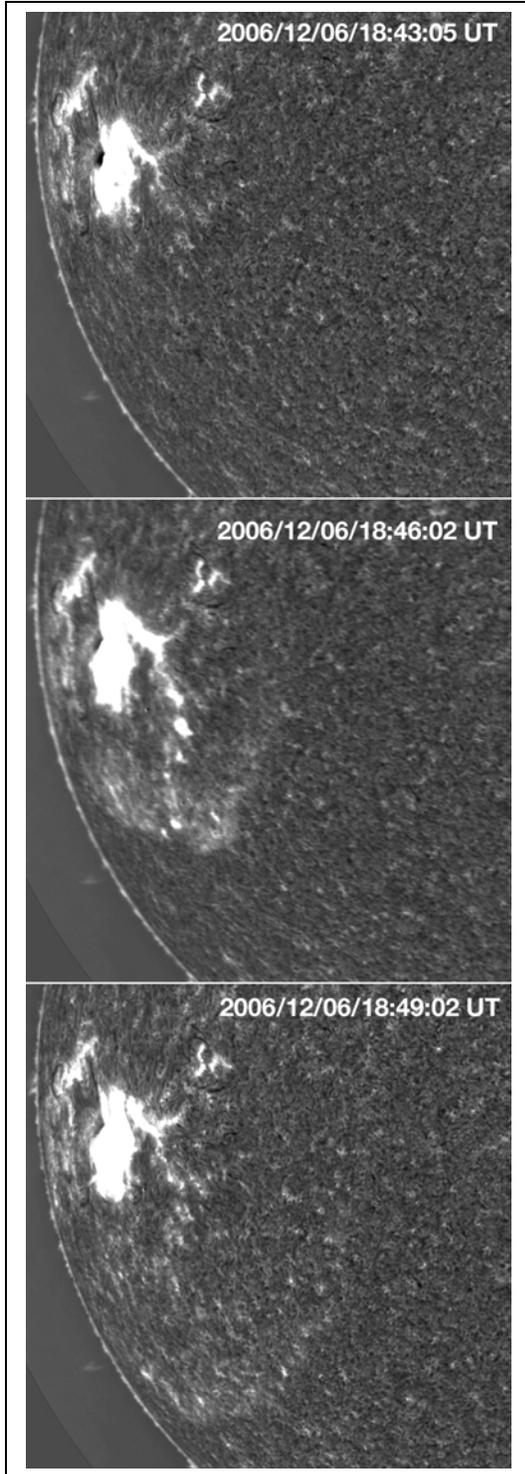
Problem 2: Derive the distance along the planet, L , to the tangent point.

Problem 3: For a typical human height of 2 meters, what is the horizon distance on A) Earth ($R=6378$ km); B) Mars (3,374 km); C) The Moon (1,738 km); Mar's moon Diemos (6 km)

Problem 4: A radio station has an antenna tower 50 meters tall. A) What is the maximum line-of-sight (LOS) reception distance in the Moon? B) On Mars?

Problem 5) What is the rate of change of the lunar LOS radius, D , for each additional meter of antenna height in Problem 4?

Problem 6) What is the rate-of-change of the distance to the lunar radio tower, L , at the LOS position in Problem 4?



Moments after a major class X-6 solar flare erupted at 18:43:59 Universal Time on December 6, 2006, the National Solar Observatory's new Optical Solar Patrol Camera captured a movie of a shock wave 'tsunami' emerging from Sunspot 930 and traveling across the solar surface. The three images to the left show the progress of this Morton Wave. The moving solar gasses can easily be seen. You can watch the entire movie and see it more clearly (<http://image.gsfc.nasa.gov/poetry/weekly/MortonWave.mpeg>).

Note: because the event is seen near the solar limb, there is quite a bit of fore-shortening so the motion will appear slower than what the images suggest.

Problem 1: From the portion of the sun's edge shown in the images, complete the solar 'circle'. What is the radius of the sun's disk in millimeters?

Problem 2: Given that the physical radius of the sun is 696,000 kilometers, what is the scale of each image in kilometers/millimeter?

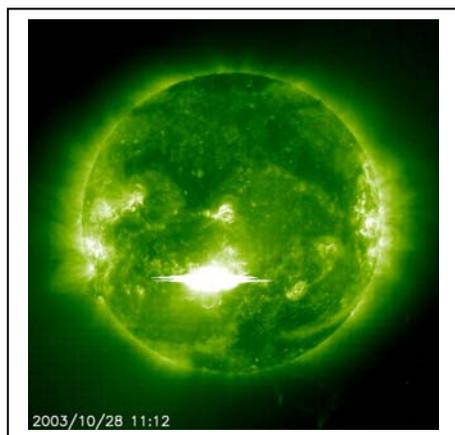
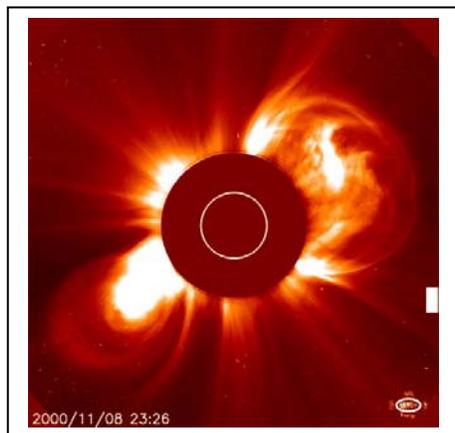
Problem 3: Select a spot near the center of the sunspot (large white spot in the image), and a location on the leading edge of the shock wave. What is the distance in kilometers from the center of the sunspot, to the leading edge of the shock wave in each image?

Problem 4: The images were taken at 18:43:05, 18:47:03 and 18:50:11 Universal Time. How much elapsed time has occurred between these images?

Problem 5: From your answers to Problem 3 and 4, what was the speed of the Morton Wave in kilometers per hour between the three images? B) did the wave accelerate or decelerate as it expanded?

Problem 6: The speed of the Space Shuttle is 44,000 kilometers/hour. The speed of a passenger jet is 900 kilometers/hour. Would the Morton Wave have overtaken the passenger jet? The Space Shuttle?

Do Fast CMEs produce intense SPEs?



The sun produces two basic kinds of storms; coronal mass ejections (SOHO satellite: top left) and solar flares (SOHO satellite: bottom left). These are spectacular events in which billions of tons of matter are launched into space (CMEs) and vast amounts of electromagnetic energy are emitted (Flares). A third type of 'space weather storm' can also occur.

Solar Proton Events (SPEs) are invisible, but intense, showers of high-energy particles near Earth that can invade satellite electronics and cause serious problems, even malfunctions and failures. Some of the most powerful solar flares can emit these particles, which streak to Earth within an hour of the flare event. Other SPE events, however, do not seem to arrive at Earth until several days later.

Here is a complete list of Solar Proton Events between 1976-2005: <http://umbra.nascom.nasa.gov/SEP/>

Here is a complete list of coronal mass ejections 1996 - 2006: http://cdaw.gsfc.nasa.gov/CME_list/

Between January 1, 1996 and June 30, 2006 there were 11,031 CMEs reported by the SOHO satellite. Of these, 1186 were halo events. Only half of the halo events are actually directed towards Earth. The other half are produced on the far side of the sun and directed away from Earth. During this same period of time, 90 SPE events were recorded by GOES satellite sensors orbiting Earth. On the next page, is a list of all the SPE events and Halo CMEs that corresponded to the SPE events. There were 65 SPEs that coincided with Halo CMEs. Also included is the calculated speed of the CME event.

From the information above, and the accompanying table, draw a Venn Diagram to represent the data, then answer the questions below.

- Question 1: A) What percentage of CMEs detected by the SOHO satellite were identified as Halo Events?
 B) What are the odds of seeing a halo Event?
 C) How many of these Halo events are directed towards Earth?

- Question 2: A) What fraction of SPEs were identified as coinciding with Halo Events?
 B) What are the odds that an SPE occurred with a Halo CME?
 C) What fraction of all halo events directed towards earth coincided with SPEs?

- Question 3: A) What percentage of SPEs coinciding with Halo CMEs are more intense than 900 PFUs?
 B) What are the odds that, if you detect a 'Halo- SPE', it will be more intense than 900 PFUs?

- Question 4: A) What percentage of Halo-SPEs have speeds greater than 1000 km/sec?
 B) What are the odds that a Halo-SPE in this sample has a speed of > 1000 km/sec?

- Question 5: From what you have calculated as your answers above, what might you conclude about Solar Proton Events and CMEs? How would you use this information as a satellite owner and operator?

Data Tables showing dates and properties of Halo CMEs and Solar Proton Events.

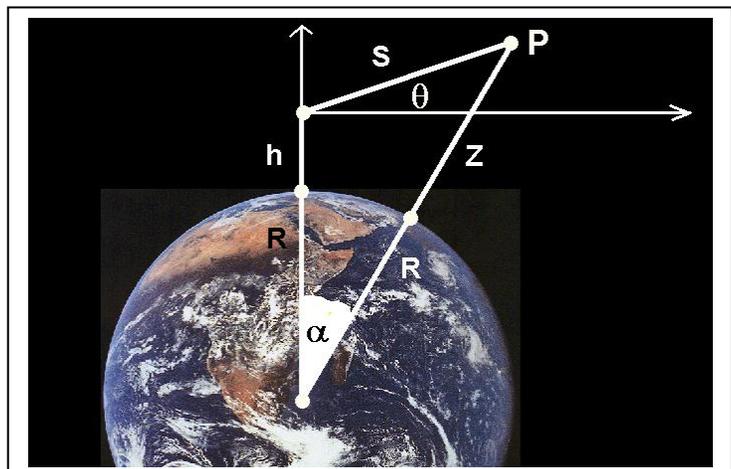
Date	CME Speed (km/s)	SPE (pfu)	Date	CME Speed (km/s)	SPE (pfu)
November 4, 1997	785	72	January 8, 2002	1794	91
November 6, 1997	1556	490	January 14, 2002	1492	15
April 20, 1998	1863	1700	February 20, 2002	952	13
May 2, 1998	938	150	March 15, 2002	957	13
May 6, 1998	1099	210	March 18, 2002	989	19
May 3, 1999	1584	14	March 22, 2002	1750	16
June 1, 1999	1772	48	April 17, 2002	1240	24
June 4, 1999	2230	64	April 21, 2002	2393	2520
February 18, 2000	890	13	May 22, 2002	1557	820
April 4, 2000	1188	55	July 15, 2002	1151	234
June 6, 2000	1119	84	August 14, 2002	1309	24
June 10, 2000	1108	46	August 22, 2002	998	36
July 14, 2000	1674	24000	August 24, 2002	1913	317
July 22, 2000	1230	17	September 5, 2002	1748	208
September 12, 2000	1550	320	November 9, 2002	1838	404
October 16, 2000	1336	15	May 28, 2003	1366	121
October 25, 2000	770	15	May 31, 2003	1835	27
November 8, 2000	1738	14800	June 17, 2003	1813	24
November 24, 2000	1289	940	October 26, 2003	1537	466
January 28, 2001	916	49	November 4, 2003	2657	353
March 29, 2001	942	35	November 21, 2003	494	13
April 2, 2001	2505	1100	April 11, 2004	1645	35
April 10, 2001	2411	355	July 25, 2004	1333	2086
April 15, 2001	1199	951	September 12, 2004	1328	273
April 18, 2001	2465	321	November 7, 2004	1759	495
April 26, 2001	1006	57	January 15, 2005	2861	5040
August 9, 2001	479	17	July 13, 2005	1423	134
September 15, 2001	478	11	July 27, 2005	1787	41
September 24, 2001	2402	12900	August 22, 2005	2378	330
October 1, 2001	1405	2360			
October 19, 2001	901	11			
October 22, 2001	618	24			
November 4, 2001	1810	31700			
November 17, 2001	1379	34			
November 22, 2001	1437	18900			
December 26, 2001	1446	779			

Note: Solar Proton Event strengths are measured in the number of particles that pass through a square centimeter every second, and is given in units called Particle Flux Units or PFUs.

The least expensive form of radiation shielding is a planetary atmosphere, but just how efficient is it? The walls of the International Space Station and the Space Shuttle provide substantial astronaut protection from space radiation, and have an equivalent thickness of 10 grams/cm^2 of aluminum, which has a density of 2.7 grams/cm^3 . Compare this shielding to the spacesuits worn by Apollo astronauts of only 0.1 grams/cm^2 . The atmosphere of Earth is a column of air with density of $0.0012 \text{ grams/cm}^3$, that is 100 kilometers tall. How much shielding does this provide at different altitudes above the ground?

In this three-part problem, we will begin the first step in constructing a mathematical model of the shielding from a planetary atmosphere. A similar calculation was published by Drs. Lisa Simonsen and John Nealy in February, 1993 in the article *"Mars Surface Radiation Exposure for Solar Maximum Conditions and 1989 Solar Proton Events"*, (NASA Technical Paper 3300)

The figure below right gives the necessary geometry and variable definitions.



The figure shows a radiation sampling point located 'h' above Earth's surface, and radiation from a source at point P, which is located at a distance 'S' from the sampling point. The distance from Earth's surface to point P is given by 'z'. Also, as seen from the sampling point, the vertical arrowed ray points to a point straight overhead, and the horizontal arrowed ray points to the horizon. The angle ' θ ' is the elevation angle of the radiation source from the sampling point. So, a scientist would place a radiation detector at the sampling point located above Earth's surface, point the instrument at the radiation source at point P, and make a measurement of the amount of radiation coming from that particular direction in the sky.

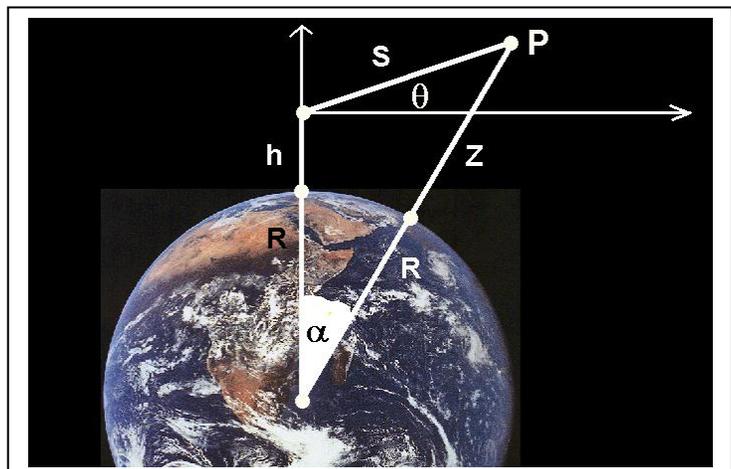
Problem 1: From the information given in the figure, calculate the distance, S, in terms of h, R, z, and θ .

Problem 2: What is the form of $S(R, h, z, \theta)$ when;

- A) If h is very much smaller than R? (h approaches zero)
- B) $\theta = 90^\circ$?
- C) If z is very much smaller than R? (z approaches zero)

The least expensive form of radiation shielding is a planetary atmosphere, but just how efficient is it? The walls of the International Space Station and the Space Shuttle provide substantial astronaut protection from space radiation, and have an equivalent thickness of 10 gm/cm^2 of aluminum, which has a density of 2.7 gm/cm^3 . Compare this shielding to the spacesuits worn by Apollo astronauts of only 0.1 gm/cm^2 . The atmosphere of Earth is a column of air with density of 0.0012 gm/cm^3 , that is 100 kilometers tall. How much shielding does this provide at different altitudes above the ground?

In the previous problem 'Atmospheric Shielding from Radiation I' we defined a function that gives the length of the path from the radiation source to the measurement point located h above Earth's surface. To find the amount of shielding provided by the atmosphere, we have to multiply this length, by the density of the atmosphere along the path S . In this problem, we will assume that the atmosphere has a constant density of 0.0012 gm/cm^3 , and see what the total shielding is along several specific directions defined by θ .



The formula for S is given by:

$$S(R,h,z,\theta) = \left((R+h)^2 \sin^2 \theta + 2R(z-h) + z^2 - h^2 \right)^{1/2} - (R+h) \sin \theta$$

Assume $R = 6,378$ kilometers.

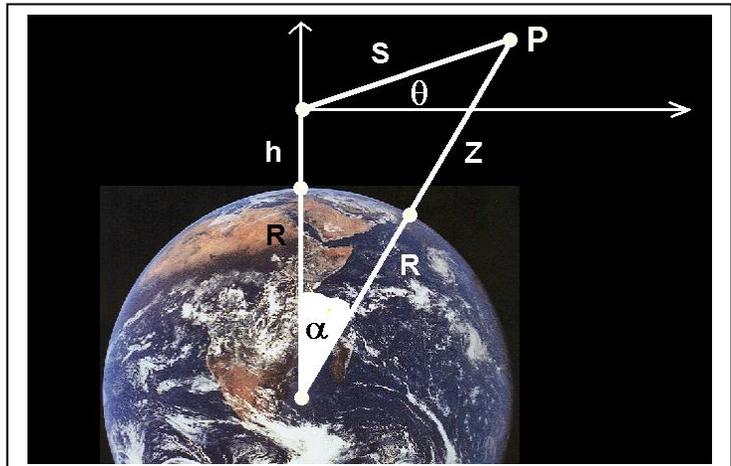
Problem 1: What is the form of the function that gives the shielding for a direction A) straight overhead ($\theta = 90^\circ$) and B) at the horizon ($\theta = 0^\circ$), for a station at sea-level ($h=0$ kilometers)?

Problem 2: More than 90% of the atmosphere is present below an altitude of about 2 kilometers. If this is approximated as being uniform in height, what is the total shielding towards the zenith (overhead) and the horizon, if $z = 2$ kilometers?

Problem 3: The atmosphere of Mars is about 100 times less dense, and mostly resides below 1 kilometer in altitude. Re-calculate the answers to Problem 2, and compare the radiation dosage difference at the surface of each planet.

The least expensive form of radiation shielding is a planetary atmosphere, but just how efficient is it? The walls of the International Space Station and the Space Shuttle provide substantial astronaut protection from space radiation, and have an equivalent thickness of 10 grams/cm² of aluminum, which has a density of 2.7 gm/cm³. Compare this shielding to the spacesuits worn by Apollo astronauts of only 0.1 gm/cm². The atmosphere of Earth is a column of air with density of 0.0012 gm/cm³, that is 100 kilometers tall. How much shielding does this provide at different altitudes above the ground?

In the previous problem 'Atmospheric Shielding from Radiation II' we estimated the atmospheric shielding of Earth and Mars and compared the potential radiation dosages on the planetary surface. In this problem, we will create a more accurate estimate by using a realistic model for the atmospheres of these planets. Assume R (Earth) = 6,378 kilometers, R (Mars) = 3,374 km



The formula for S is given by $S(R,h,z,\theta) = ((R+h)^2 \sin^2\theta + 2R(z-h) + z^2 - h^2)^{1/2} - (R+h) \sin\theta$

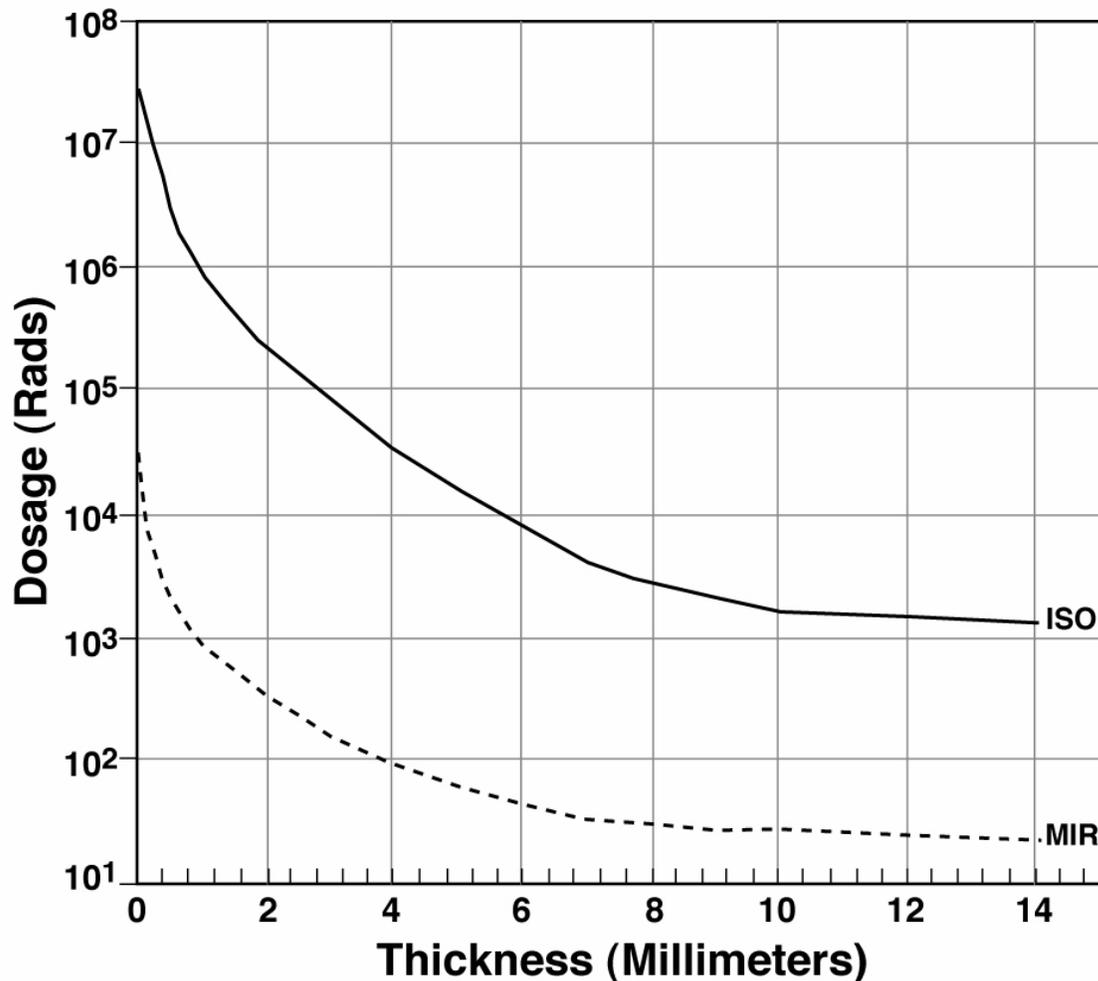
Problem 1: What is the form of the function S for h=0 ?

The density of a planetary atmosphere is defined by the exponential function $N(z) = N(0) e^{(-z/H)}$ where H is the scale-height of the gas. For the composition of Earth's atmosphere, temperature, and surface gravity, H = 8.5 km. For Mars, H = 11.1 km. The sea-level density for Earth, $N(0) = 0.0012 \text{ gm/cm}^3$, while for Mars, $N(0) = 0.00020 \text{ g/cm}^3$. The amount of surface shielding for radiation arriving from a direction, θ , is given by evaluating the integral below:

Problem 2:

- A) Determine the form for S for the case of $\theta = 90$ which gives the minimum planetary shielding at the surface for radiation entering from directly overhead.
- B) Evaluate the integral for Earth and for Mars.
- C) Assuming that the radiation environments of Mars and Earth are otherwise similar, about how many times more would your radiation dosage be on the surface of Mars compared to Earth?
- D) How does the atmospheric shielding of Earth compare to the shielding provided by the International Space Station or the Space Shuttle?

$$D = \int_0^{+\text{inf.}} N(z) ds$$



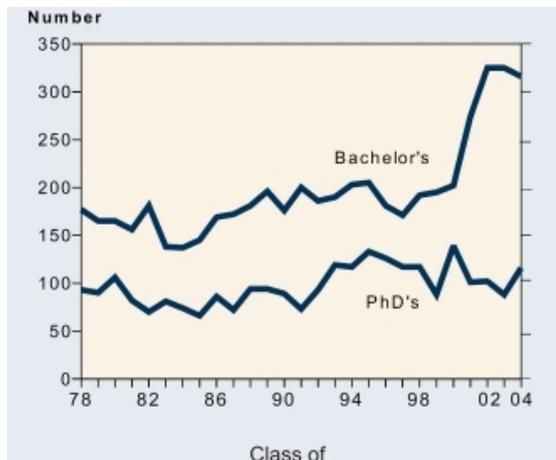
Satellites are designed to withstand many forms of radiation in the harsh environment of space. The above graph shows how the total life time radiation dosage inside a spacecraft changes as the amount of aluminum shielding increases. The data comes from the former MIR space station and the research satellite ISO. The sensitive instruments and electronic systems operate inside the satellite shell and are protected from harmful dosages of radiation by the shielding provided by the spacecraft walls.

Problem 1: You want to design a new satellite to replace the ISO satellite and to last 8 years in orbit, but it can only continue to work normally if it accumulates no more that 75,000 Rads of radiation during that time. Using the curve for ISO, how thick do the satellite walls have to be to insure this?

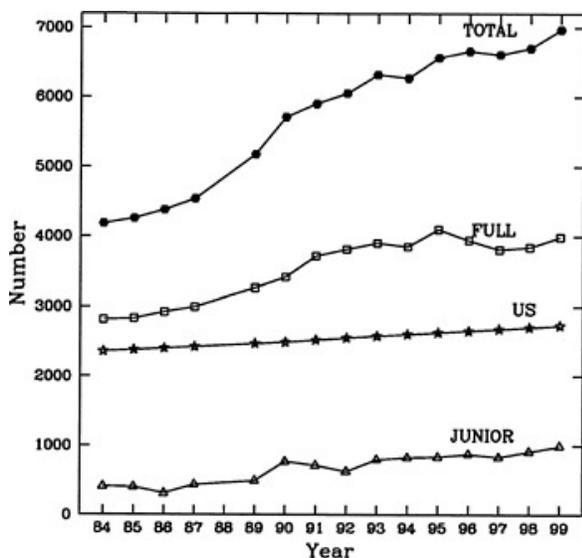
Problem 2: The International Space Station has the same orbit as the MIR. An astronaut will spend about 100 hours in space to assemble the station. If the equivalent shielding of her spacesuit is 1.0 mm of aluminum, how large of a dosage will she receive during this time? How does it compare to the 0.4 Rads she would receive if she stayed on the ground?

Problem 3: A cubical satellite has sides 1 meter across, and the density of the aluminum is 2.7 g/cc. How much mass, in kilograms, will the satellite have with 4 mm-thick walls? 12 mm-thick walls? If the launch cost is \$15,000 per kilogram, how much extra will it cost to launch the heavier, and better-shielded, satellite?

Astronomy as a Career



Imagine a job where you could study space and make discoveries about how the universe is put together. Perhaps uncover the nature of Dark Matter, discover life under the surface of Mars, or detect the first Earth-like planet orbiting a nearby star. Astronomy is the profession that lets you explore the universe, travel the world to present your discoveries to other scientists, and to use amazing technology to study the distant universe. It takes 4 years of college to get a Bachelors Degree in astronomy, and up to 7 years to get a PhD - your ticket to an exciting life-long career in space science. It is hard work, but most of us that have chosen this career cannot imagine any other career that for us is equally worth doing or as exciting. Here is what the American Institute of Physics has to say about the statistics of astronomy:



"In astronomy, the PhD class of 2001 included 101 students with 24% women and 27% foreign citizens. Almost three quarters of the combined PhD classes reported accepting postdoctoral appointments. The survey finds that "astronomy PhDs felt very positive about their degree and employment situation." The class of 2001 produced 274 astronomy bachelors, and the class of 2002 produced 325, with 42% women and 6% foreign citizens in the combined classes." (<http://www.aip.org/fyi/2005/067.html>)

The top figure is the number of Bachelors and PhDs in astronomy granted each year. The bottom figure is the number of professional members of the US American Astronomical Society in the 'Junior' and 'Full' categories. Also shown is the US population growth (x 1/100,000).

From this graphical information, answer the following questions:

- 1 - According to Figure 1 in the year 2000, about how many PhDs in astronomy were awarded?
- 2 - According to Figure 1, about what was the percentage of PhDs received in astronomy compared to those awarded a Bachelor's degree in 2004?
- 3 - According to the text, what two groups have seen the largest changes in terms of Bachelors degree awards?
- 4 - In Figure 2, does population increase during 1985 - 2000 account for the changes in the number of professional astronomers in the USA? What other factors might be involved to stimulate interest in astronomy as a career since 1985?

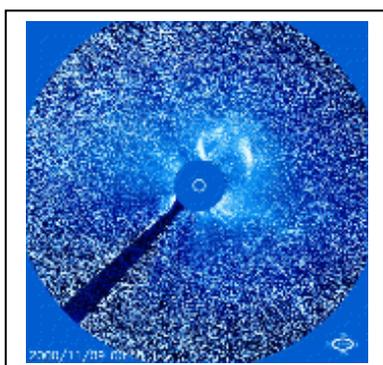
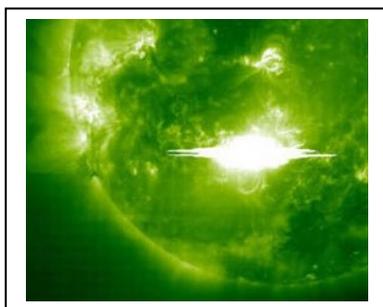
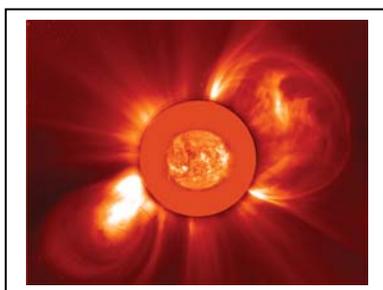
One of the most basic activities that scientists perform with their data is to look for correlations between different kinds of events or measurements in order to see if a pattern exists that could suggest that some new 'law' of nature might be operating. Many different observations of the Sun and Earth provide information on some basic phenomena that are frequently observed. The question is whether these phenomena are related to each other in some way. Can we use the sighting of one phenomenon as a prediction of whether another kind of phenomenon will happen?

During most of the previous sunspot cycle (January-1996 to June-2006), astronomers detected 11,031 coronal mass ejections, (CME: Top image) of these 1186 were 'halo' events. Half of these were directed towards Earth.

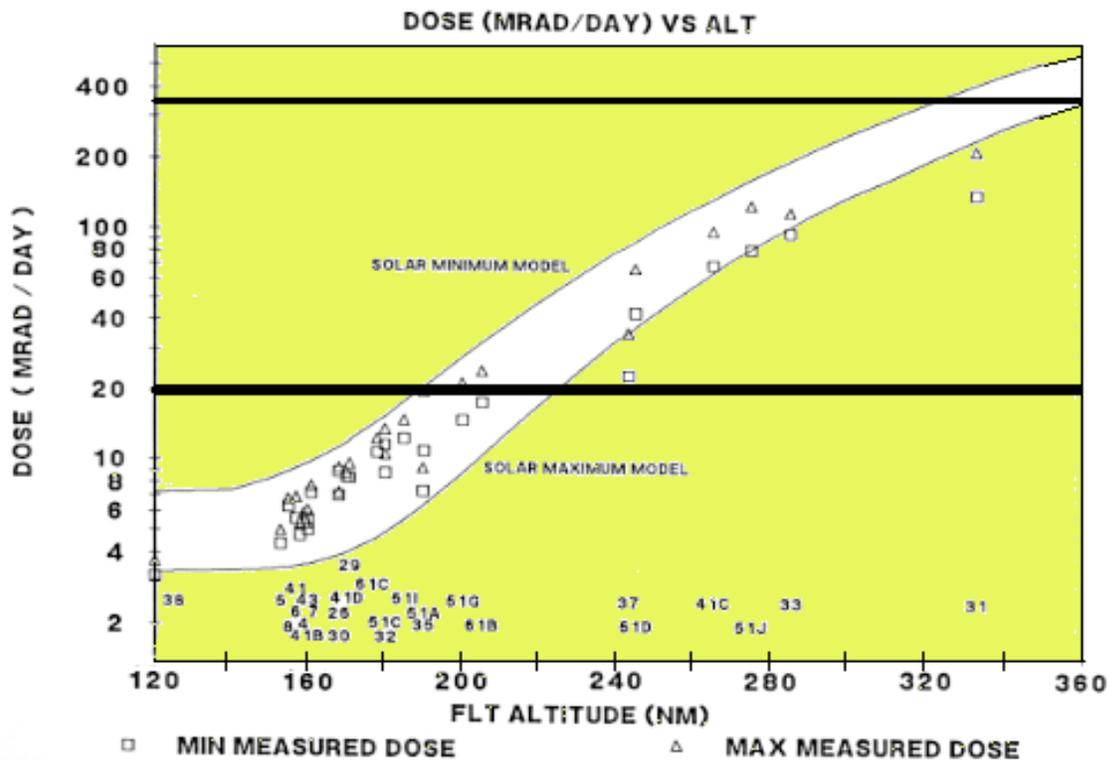
During the same period of time, 95 solar proton events (streaks in the bottom image were caused by a single event) were recorded by the GOES satellite network orbiting Earth. Of these SPEs, 61 coincided with Halo CME events.

Solar flares (middle image) were also recorded by the GOES satellites. During this time period, 21,886 flares were detected, of which 122 were X-class flares. Of the X-class flares, 96 coincided with Halo CMEs, and 22 X-class flares also coincided with 22 combined SPE+Halo CME events. There were 6 X-flares associated with SPEs but not associated with Halo CMEs. A total of 28 SPEs were not associated with either Halo CMEs or with X-class solar flares.

From this statistical information, construct a Venn Diagram to interrelate the numbers in the above findings based on recent NASA satellite observations, then answer the questions below.



- 1 - What are the odds that a CME is directed towards Earth?
- 2 - What fraction of the time does the sun produce X-class flares?
- 3 - How many X-class flares are not involved with CMEs or SPEs?
- 4 - If a satellite spotted both a halo coronal mass ejection and an X-class solar flare, what is the probability that a solar proton event will occur?
- 5 - What percentage of the time are SPEs involved with Halo CMEs, X-class flares or both?
- 6 - If a satellite just spots a Halo CME, what are the odds that an X-class flare or an SPE or both will be observed?
- 7 - Is it more likely to detect an SPE if a halo CME is observed, or if an X-class flare is observed?
- 8 - If you see either a Halo CME or an X-class flare, but not both, what are the odds you will also see an SPE?
- 9 - If you observed 100 CMEs, X-class flares and SPEs, how many times might you expect to see all three phenomena?



The typical radiation dosage on the ground is about 1.0 milliRad/day or 360 milliRad/year. This dosage is considered safe, and it is an unavoidable part of the natural background that we live and work within. In space, however, this normal background dosage is significantly exceeded. The figure above shows the radiation dosages encountered by Space Shuttle astronauts during various missions indicated by the numbers near the bottom of the graph. For example, at the far right, astronauts onboard Shuttle Mission STS-31 at an orbital altitude of 335 Nautical Miles (NM), experienced dosages between 150 to 200 milliRads per day.

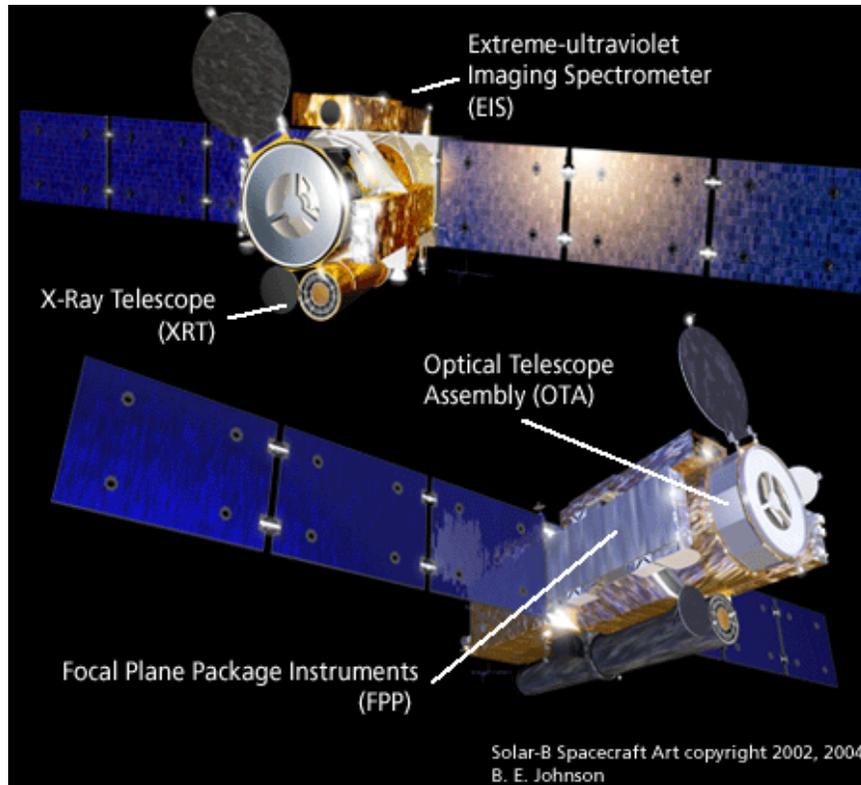
Problem 1 - At about what altitude do most Space Shuttles orbit?

Problem 2 - What is the average daily dose at this altitude in milliRads/day?

Problem 3 - For a typical Shuttle mission of 10 days, what will be the astronaut's average dose?

Problem 4 - If the astronaut remained on the ground during this mission, how much of a dosage would he have acquired?

Problem 5 - How much radiation dosage did the STS-31 astronauts accumulate during their 118-hour mission to place the Hubble Space Telescope in orbit?

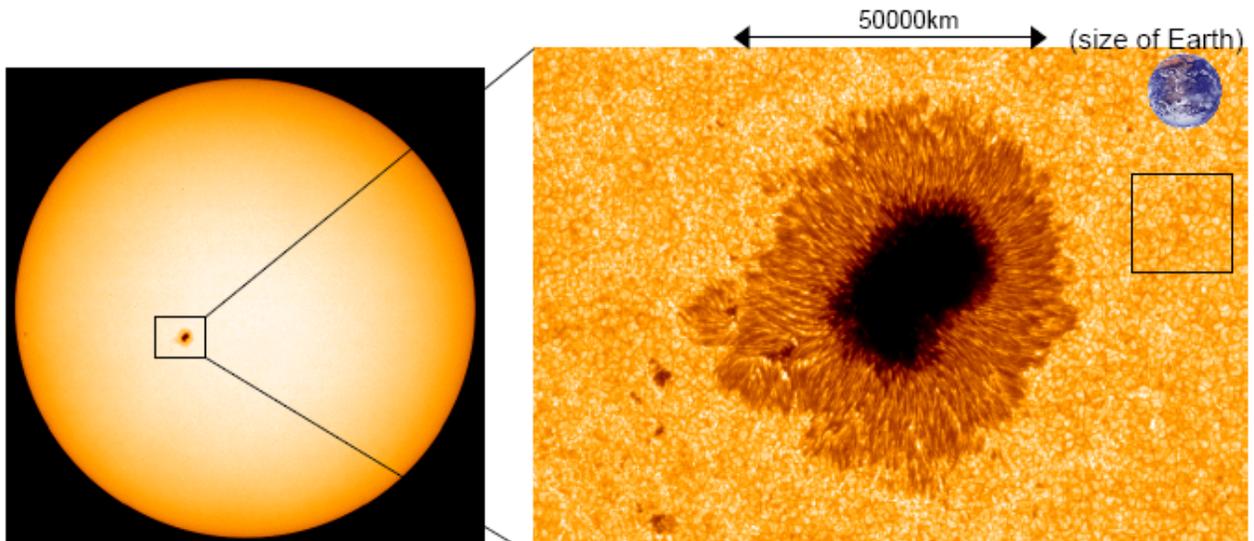


The Hinode satellite weighs approximately 700 kg (dry) and carries 170 kg of gas for its steering thrusters, which help to maintain the satellite in a polar, sun-synchronous orbit for up to two years. The satellite has two solar panels (blue) that produce all of the spacecraft's power. The panels are 4 meters long and 1 meter wide, and are covered on both sides by solar cells.

Problem 1 - What is the total area of the solar panels covered by solar cells in square centimeters?

Problem 2 - If a solar cell produces 0.03 watts of power for each square centimeter of area, what is the total power produced by the solar panels when facing the sun? Can the satellite supply enough power to operate the experiments which require 1,150 watts?

Problem 3 - Suppose engineers decided to cover the surface of the cylindrical satellite body with solar cells instead. If the satellite is 4 meters long and a diameter of 1 meter, how much power could it produce if only half of the area was in sunlight at a time? Can the satellite supply enough power to keep the experiments running, which require 1,150 watts?



After a successful launch on September 22, 2006 the Hinode solar observatory caught a glimpse of a large sunspot on November 4, 2006. An instrument called the Solar Optical Telescope (SOT) captured this image, showing sunspot details on the solar surface.

Problem 1 - From the clues in this image, what is the scale of the image on the right in units of kilometers per millimeter?

Problem 2 - What is the size of the smallest detail you can see in the image?

Problem 3 - Compared to familiar things on the surface of Earth, how big would the smallest feature in the solar image be?

Problem 4 - The gold-colored textured surface is the photosphere of the sun. The texturing is produced by heated gas that is convecting from the hot interior to the cooler outer layers of the sun. The convecting gases form cells, called granulations, at the surface, with upwelling gas flowing from the center of each cell, outwards to the cell boundary, where it cools and flows back down to deeper layers. What is the average size of a granulation cell within the square?

Problem 5 - Measure several granulation cells at different distances from the sunspot, and plot the average size you get versus distance from the spot center. Do granulation cells have about the same size near the sunspot, or do they tend to become larger or smaller as you approach the sunspot?

Compound Interest

How it works: Suppose this year I put \$100.00 in the bank. The bank invests this money and at the end of the year gives me \$4.00 back in addition to what I gave them. I now have \$104.00. My initial \$100.00 increased in value by $100\% \times (\$104.00 - \$100.00) / \$100.00 = 4\%$. Suppose I gave all of this back to the bank and they reinvested in again. At the end of the second year they have me another 4% increase. How much money do I now have? I get back an additional 4%, but this time it is 4% of \$104.00 which is $\$104.00 \times 0.04 = \4.16 . Another way to write this after the second year is:

$$\$100.00 \times (1.04) \times (1.04) = \$108.16.$$

After 6 years, at a gain of 4% each year, my original \$100.00 is now worth:

$$\$100.00 \times (1.04) \times (1.04) \times (1.04) \times (1.04) \times (1.04) \times (1.04) = \$126.53$$

Do you see the pattern? The basic formula that lets you calculate this 'compound interest' easily is:

$$F = B \times (1 + P/100)^T$$

where :

B = the starting amount, P= the annual percentage increase, T = number of investment years.

Question: In the formula, why did we divide the interest percentage by 100 and then add it to 1?

Problem 1: The US Space program invested \$26 billion to build the Apollo Program to send 7 missions to land on the Moon.

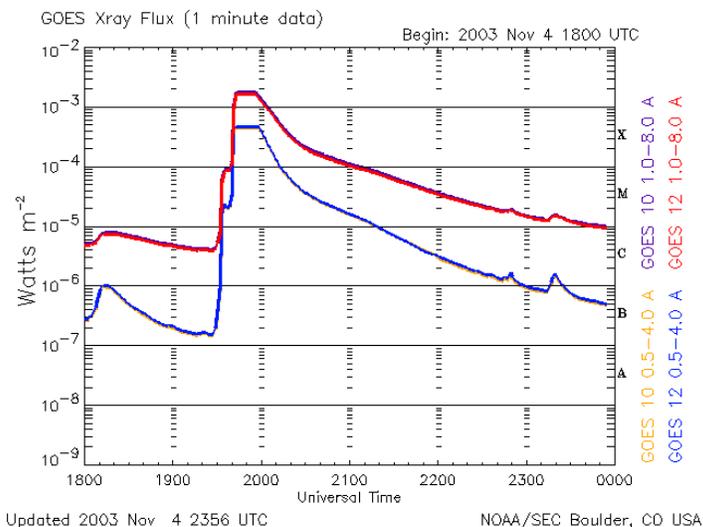
A) What was the average cost for each Apollo mission?

B) You have probably heard your parents complain that 'prices have sure gone up this year!'. This is because, each year, the price for food, gasoline, and other things you buy as a family have been increasing each year by about 3%. This is called Inflation. It means that this year you have to pay \$1.03 for something you bought for \$1.00 last year. Since the last moon landing in 1972, inflation has averaged about 4% each year. From you answer to A), how much would it cost to do the same Apollo moon landing in 2007?

Problem 2: A NASA satellite program was originally supposed to cost \$250 million when it started in 2000. Because of delays in approvals by Congress and NASA, the program didn't get started until 2005. If the inflation rate was 5% per year, A) how much more did the mission cost in 2005 because of the delays? B) Was it a good idea to delay the mission to save money in 2000?

Problem 3: A scientist began his career with a salary of \$40,000 in 1980, and by 2000 this had grown to \$100,000. A) What was his annual salary gain each year? B) If the annual inflation rate was 3%, why do you think that his salary gain was faster than inflation during this time?

Solar Flare Reconstruction



X-ray Flare Data.

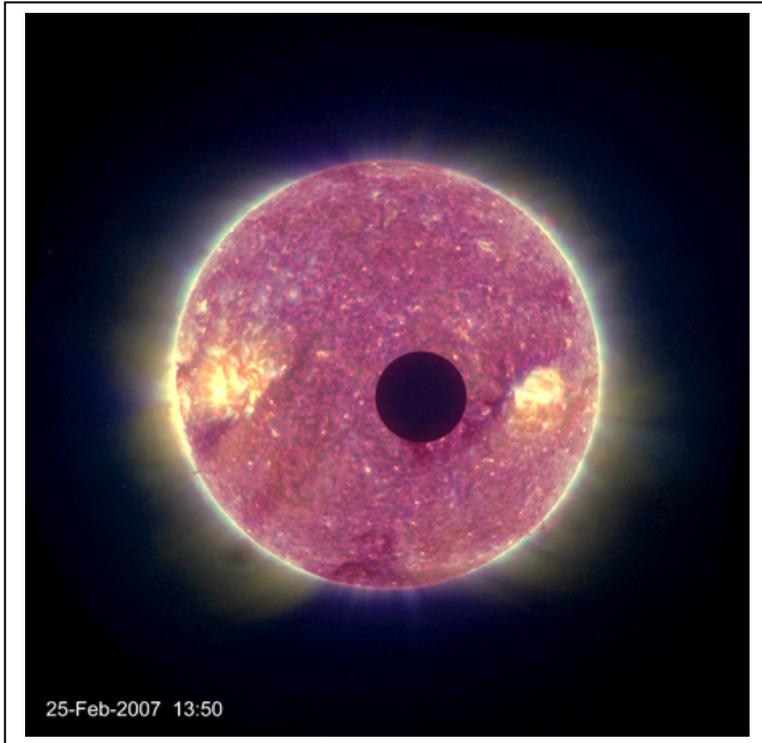
Universal Time (UT)	Intensity (Watts/m ² /sec)
19:40	0.00010
19:41	0.00060
19:42	0.00180
19:45	saturated
19:50	saturated
19:55	0.00180
20:00	0.00140
20:05	0.00090
20:10	0.00060
20:15	0.00040
20:20	0.00030
20:25	0.00025
20:30	0.00020
20:35	0.00019
20:40	0.00017
20:45	0.00016
20:50	0.00015
20:55	0.00014
21:00	0.00012
21:05	0.00010

During the November 4, 2003 solar flare, the GOES satellite measured the intensity of the flare as its light increased to a maximum and then decreased. The problem is that the solar flare was so bright that it could not record the most intense phase of the brightness evolution - what astronomers call its light curve. The figure above shows the light curve for two different x-ray energies, and you can see how its most intense phase near 19:50 UT has been clipped. This is a common problem with satellite detectors and is called 'saturation'. To work around this problem to recover at least some information about the flare's peak intensity, scientists resorted to mathematically fitting the pieces of the light curve that they were able to measure, and interpolated the data using their mathematical model, to estimate the peak intensity of the flare.

Problem 1 (Pre-Algebra): Re-plot the data in the table and from the trend on either side of the saturated region, estimate the peak intensity.

Problem 2 (Algebra): Re-plot the data, and from the information on either side of the saturation region, create two exponential functions that fit the data. Use the elapsed time since 19:40 as the independent variable. Find the intersections of these two functions to estimate the peak intensity and time.

Problem 3 (Calculus): Integrate the piecewise function in Problem 2 to determine the area under the light curve to 21:05. Note: 1 Watt equals 1 Joule of energy per second. Given that the sun is 147 million kilometers from the GOES satellite, calculate the surface area, in square meters, of a sphere of this radius. Calculate the total energy, in Joules, radiated by the flare that passed through the surface area of the sphere.



The twin STEREO satellites captured this picture of our Moon passing across the sun's disk on February 25, 2007. The two satellites are located approximately in the orbit of Earth, but are moving away from Earth in opposite directions. From this image, you can figure out how far away from the Moon the STEREO-B satellite was when it took this picture! To do this, all you need to know is the following:

- 1) The diameter of the Moon is 3,476 km
- 2) The distance to the sun is 148 million km.
- 3) The diameter of the sun is 0.54 degrees

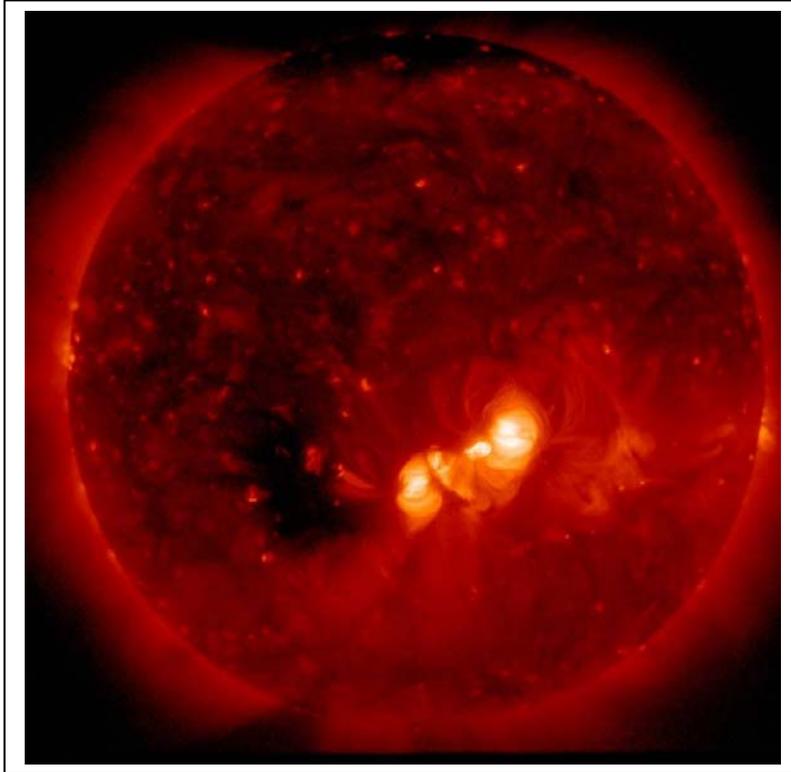
Can you figure out how to do this using geometry?

Problem 1: Although the True Size of an object is measured in meters or kilometers, the Apparent Size of an object is measured in terms of the number of angular degrees it subtends. Although the True Size of an object remains the same no matter how far away it is from you, the Apparent Size gets smaller the further away it is. In the image above, the Apparent Size of the sun was 0.54 degrees across on February 25. By using a millimeter ruler and a calculator, what is the angular size of the Moon?

Problem 2: As seen from the distance of Earth, the Moon has an Apparent Size of 0.53 degrees. If the Earth-Moon distance is 384,000 kilometers, how big would the Moon appear at twice this distance?

Problem 3: From your answer to Problem 1, and Problem 2, what is the distance to the moon from where the above photo was taken by the STEREO-B satellite?

Problem 4: On February 25, 2007 there was a Half Moon as viewed from Earth, can you draw a scaled model of the Earth, Moon, Stereo-B and Sun distances and positions (but not diameters to the same scale!) with a compass, ruler and protractor?

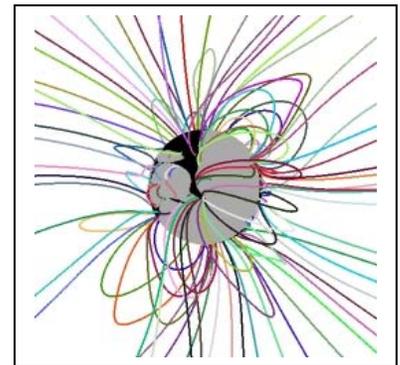
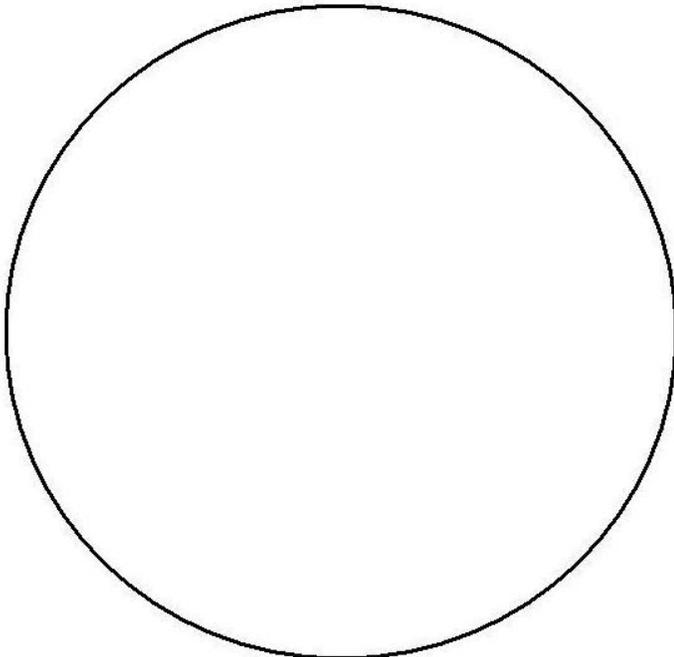


This image was taken by the X-Ray Telescope (XRT) on the Hinode solar observatory in December, 2006. It shows the complex magnetic structure over a large sunspot called Active Region AR930. You can also see large numbers of bright 'freckles' - each representing a small micro-flare.

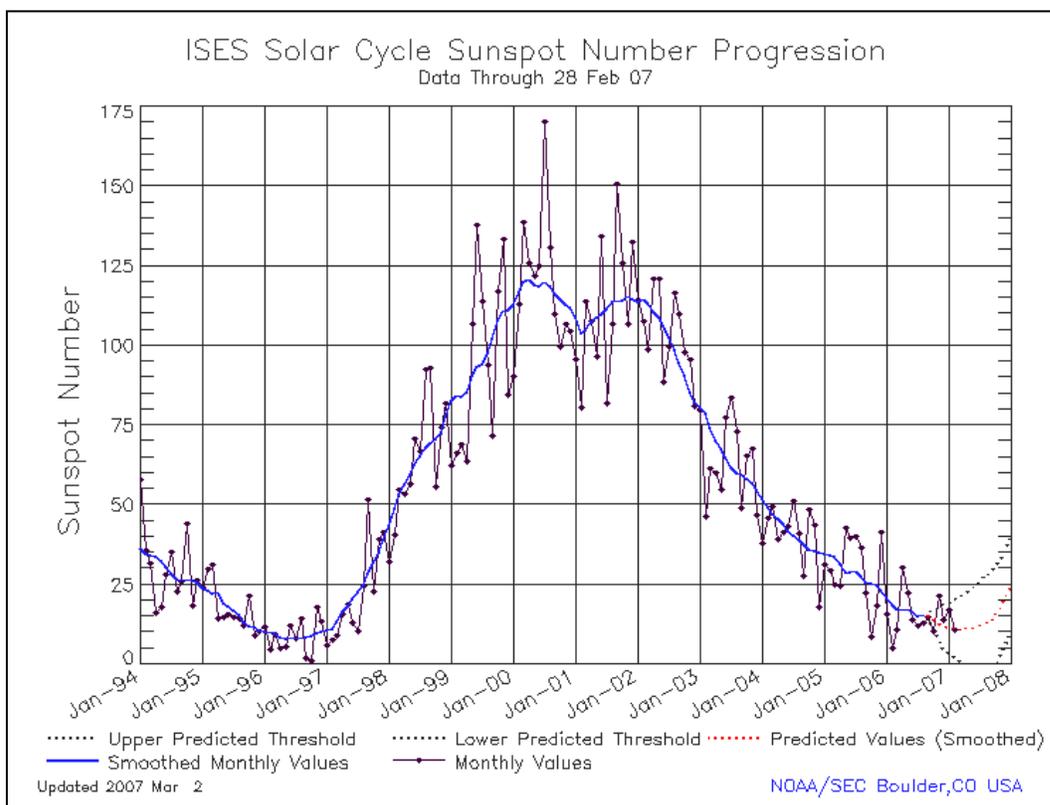
The large black 'holes' are places in the corona of the sun where high-temperature gas is free to escape from the sun, and so there is little gas to illuminate these regions of the solar corona. This is because in these 'coronal holes' magnetic field lines open out to interplanetary space. Closed field lines near the surface act like magnetic bottles and keep the heated plasma close to the sun, creating the bright areas (red and yellow colors).

Using a black pen or pencil, try your hand at predicting what the magnetic field lines look like using the clues from Hinode picture!

Below is an example of a field line model calculated from an image by the SOHO satellite.



The Sunspot Cycle - endings and beginnings



The above plot shows the current sunspot cycle (Number 23) based on the average monthly sunspot counts since January, 1994.

Problem 1 - About when (month and year) did Sunspot Cycle 23 begin?

Problem 2 - About when (month and year) did Sunspot Cycle 23 reach its maximum?

Problem 3 - A) What was the average minimum sunspot count during the years of the previous sunspot minimum? B) What do you think the average sunspot count will be during the current sunspot minimum?

Problem 4 - What is the number of years between sunspot minima to the nearest tenth of a year?

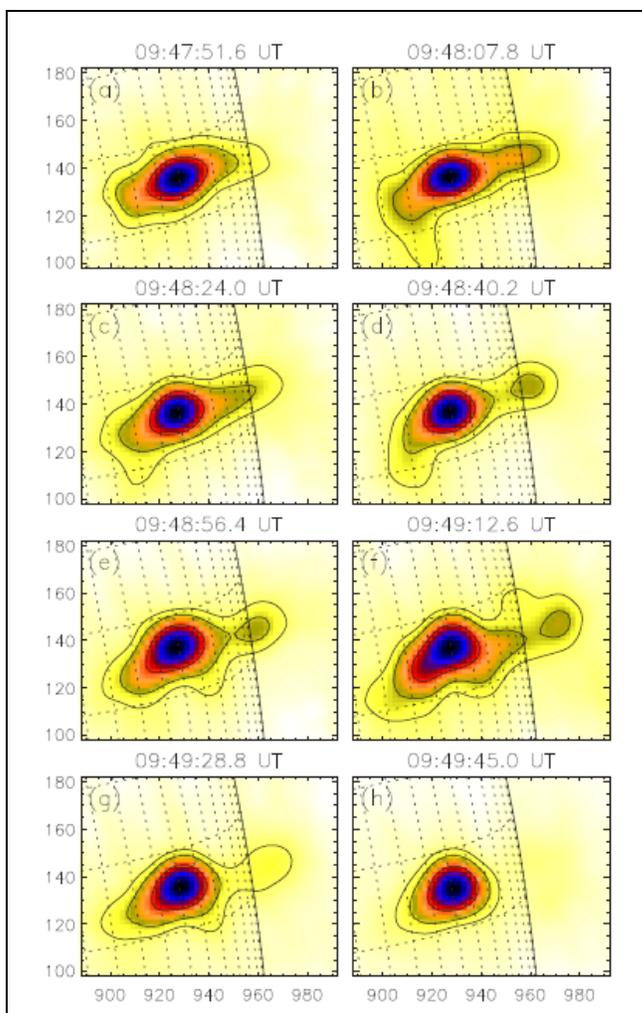
Problem 5 - How long did Cycle 23 take to reach sunspot maximum?

Problem 6 - When (year, month) do you predict we will reach sunspot maximum during the next cycle (Cycle 24)?

Problem 7 - When (year, month) do you think the next sunspot minimum will occur?

Problem 8 - During which part of the sunspot cycle is there A) the greatest month-to-month variation in the number of sunspots counted? B) The least variation in the number counted?

Super-fast solar flares !



NASA's Ramaty High Energy Solar Spectroscopic Imager (RHESSI) satellite has been studying solar flares since 2002. The sequence of figures to the left shows a flaring region observed on November 3, 2003. This flare was rated as 'X3.9' making it an extremely powerful event. A detailed study of this flare by astronomer Dr. Astrid Veronig and her colleagues at the Institute of Physics of the University of Graz in Austria allowed scientists to determine the physical properties of this event.

During the 4-minute flaring event, gas temperatures of over 45 million degrees Kelvin were reached in a plasma with a density of 400 billion atoms/cc.

The figures each have a field of view of 80 seconds of arc x 100 seconds of arc. The diameter of the sun in these angular units is 1950 seconds of arc, and its physical diameter is 1,392,000 kilometers.

Each image shows the main flare region (blue) and Images D, E and F show a second 'blob' being ejected by the flaring region.

"X-ray sources and magnetic reconnection in the X3.9 flare of 2003 November 3" A. Veronig et al., Astronomy and Astrophysics, 2005 vol. 446, p.675.

Problem 1 - From the information in the text, what is the size of each box in kilometers?

Problem 2 - What is the scale of each image in kilometers per millimeter?

Problem 3 - Between Image D and Image F, how much time elapsed?

Problem 4 - Between Image D and Image F, how far did the plasma Blob travel in kilometers?

Problem 5 - Between Image D and Image F, what was the average speed of the Blob in kilometers per second?

Problem 6 - The SR-71 Blackbird holds the official Air Speed Record for a manned airbreathing jet aircraft with a speed of 3,529.56 km/h (2,188 mph). It was capable of taking off and landing unassisted on conventional runways. The record was set on July 28, 1976 by Eldon W. Joersz near Beale Air Force Base in California. Would the SR-71 have been able to out-run the plasma blob?

A note from the Author:

Hi again!

I hope you and your students are enjoying this collection of unusual math problems!

Through my middle school and high school years, I was constantly inspired and enthralled by space and astronomy. Not surprisingly, since it was the 1960's and these years in my life were bracketed by John Glen's famous orbit of Earth, and the Apollo-11 moon landing..and, oh yes, movies like '2001: A Space Odyssey' and TV programs like 'Outer Limits' and 'Star Trek'. (I never took 'Lost In Space' seriously!)

Although I have been a professional astronomer since 1982, Mathematics was not especially easy for me in elementary school, and in grades 7-12. I would regularly get Bs and a few As. But in those days that was enough to guarantee you admission into virtually all colleges, since only about 15% of high school seniors went on to a 4-year college. I went to U.C. Berkeley because it was only a 40-minute bus ride from my parent's front door where I would live as an undergraduate. Luckily for me, UC had one of the best Astronomy and Mathematics Departments in the world!

Despite my non-stellar grade-school abilities, I always enjoyed math and had a positive attitude about it. I was intrigued by algebra and trigonometry, but that was just a warm-up. When I got my first taste of calculus during the end of my Senior Year at Fremont High School in Oakland California, it was like some kind of epiphany. I was overpoweringly struck by how beautiful the various mathematical symbols were; the graceful integral signs, the elegantly loopy partial derivative sign, the mysterious capital-deltas and the choppy-looking sigmas. Each had a story to tell, and I was so excited that after 12 years of school, I could start to understand the beauty in this math. This inspiration and attitude paid off.

When I started college, my grades in math soared to straight-As with the occasional B. I credit all of that to a positive and inquisitive attitude towards math, but also to the simple fact that I had perhaps out-grown older ways of thinking that had silently held me back, and I had somehow 'matured' into the subject.

So, what does this long-ago experience have to do with today's student learning in mathematics? Perhaps it reflects on providing additional motivation to a struggling student, one of which would well have been me in today's educational system. Perhaps it means that, when a student has a sense of what they want to be, they can more easily see why math is going to be an important aspect of that future career dream. Perhaps it also means that students are still developing and unfolding at a time when they are asked to master mathematical concepts that may well be temporarily too advanced for where they are at that moment.

Whatever the situation, I would personally like you to know that achieving a career in science is a marathon, not a 100-yard dash. Some of the brightest students that race out of the gate first, may well not have the stamina that a slightly less adept student has, who has a dream of someday walking on the moon, or peering into the deepest recesses of the atom.

*Sincerely,
Dr. Sten Odenwald
NASA Astronomer*



National Aeronautics and Space Administration

**Space Math @ NASA
Goddard Spaceflight Center
Greenbelt, Maryland 20771
<http://spacemath.gsfc.nasa.gov>**

www.nasa.gov