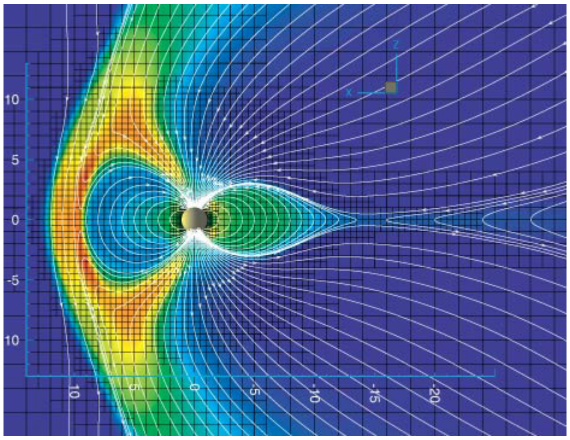
The Pressure of a Solar Storm



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?

Answer Key:

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	**1.9**	**0.002**	**5.0**
1-16-2005	X-2.8	70	3700	70	**15.3**	**0.02**	**3.5**
10-28-2003	X-17	100	2700	70	**11.7**	**0.02**	**3.7**
11-4-2003	X-28	80	2300	49	6.8	0.01	4.0
4-21-2002	X-1.5	20	2421	10	**1.9**	**0.0004**	**5.0**
7-23-2002	X-4.8	40	1200	15	**0.9**	**0.0009**	**5.6**
4-6-2001	X-5.6	20	1184	20	**0.4**	**0.002**	**6.3**
7-14-2000	X-5.7	30	2300	60	**2.5**	**0.01**	**4.7**
11-24-2000	X-1.8	50	2000	10	3.2	0.0004	4.6
8-24-1998	X-1	15	1500	10	0.5	0.0004	6.1

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.

Answer: See above shaded table entries. This is a good opportunity to use an Excel spreadsheet to set up the calculations. This also lets students change the entries to see how the relationships change, as an aid to answering the remaining questions.

Problem 2: A geosynchronous communications satellite is orbiting at a distance of 6.6 Re. For which storms will the satellite be directly affected by the solar storm particles?

Answer: All of the storms except for the ones on April 6, 2001 and August 24, 1998

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

Answer: The values for the ram pressure (Pr) are all substantially larger than the values for the magnetic pressure (Pm), so we conclude that ram pressure is stronger than the cloud's magnetic pressure. This means that when the clouds impacts another object, such as Earth, it is mostly the ram pressure of the cloud that determines the outcome of the interaction.

Note to Teacher: Ram pressure is the pressure produced by a cloud of particles traveling at a particular speed with a particular density. We call this a 'ram' pressure because it is also the pressure that you feel as you 'ram' your way through the air when you are in motion. Because only the relative speed is important, you will feel the same pressure if you are 'stationary' and a gas is moving past you at a particular speed, or if the gas is 'stationary' and you are trying to move through it at the same speed. Technically, ram pressure is the product of the gas density and the square of this relative speed.