Magnetic Mirrors, the Ionosphere, and the Magnetosphere

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1. Introduction

The force **F** exerted by an external magnetic field **B** on a magnetic dipole **m** is given by:

$$\mathbf{F} = [\nabla(\mathbf{m} \cdot \mathbf{B})]_{\mathbf{x}=\mathbf{x}_m}$$

There is also a net torque that the dipole experiences from the applied magnetic field that tends to align the two. Once aligned, this equation becomes:

$$\mathbf{F} = [m \nabla |\mathbf{B}|]_{\mathbf{x}=\mathbf{x}_m}$$

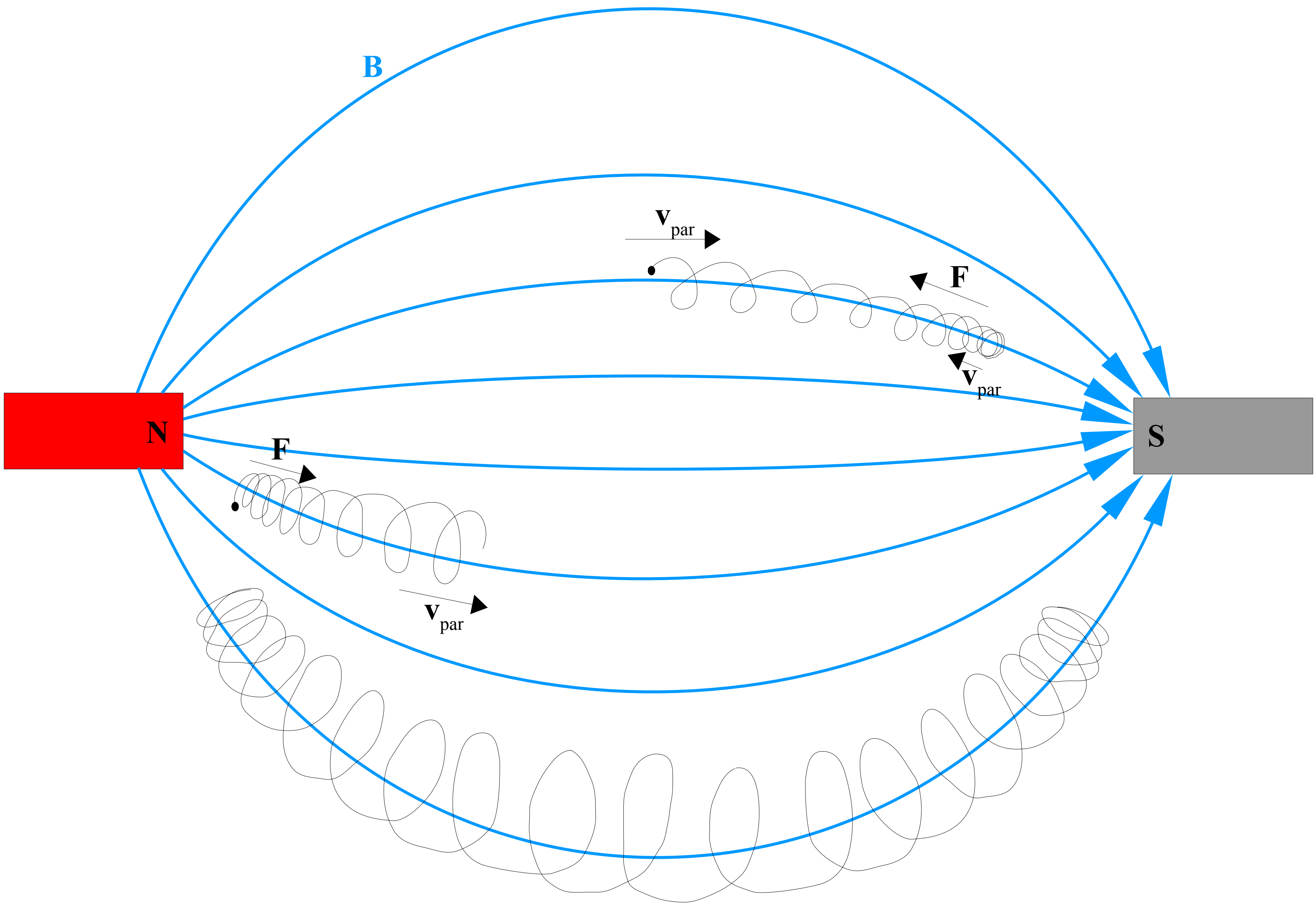
The gradient always points downhill, i.e. away from regions where its operand is the highest. As a result, the magnetic dipole experiences a force away from regions of high magnetic field strength, independent of whether it is a positive field or a negative field and independent of the particle's charge. Additionally, at locations in space where the magnetic field strength changes the most rapidly, the gradient is the highest, and therefore the force is the highest. On a diagram, regions that have the magnetic field becoming stronger are represented by converging field lines. The more the field lines converge, the stronger the repelling force. The effect is summarized as:

Magnetic dipoles are repelled from areas with converging magnetic field lines

A single, free, charged particle in an external magnetic field feels a total force $\mathbf{F} = q\,\mathbf{v} \times \mathbf{B}$. Coupled with Newton's law, this interaction leads to charged particles following spiraling paths around magnetic field lines. If one loop of the spiral is small compared to the spatial variations in the magnetic field, the particle acts like a little loop of current and therefore acts like a magnetic dipole. Their motion can thus be summarized:

Free charged particles spiral along magnetic field lines and are repelled from areas with converging magnetic field lines

A region of high magnetic field strength, such as at the tip of an magnet, therefore acts like a magnetic mirror. Two or more magnetic mirrors can be used to trap charged particles and are very useful in plasma confinement, as shown below.



The earth acts like a giant dipole magnet with a magnetic dipole pattern. The earth's magnetic field lines converge at the magnetic North and South poles. As a result, charged particles become trapped into the Van Allen radiation belts and the ionosphere. The earth's magnetic field is to a good approximation azimuthally symmetric, so that each cloud of trapped particles stretches out azimuthally into a belt. Note that most of the ionosphere experiences significant gravitational forces in addition to magnetic forces so that the ions form more of a spherical belt than in the Van Allen radiation belts. Also, because the ionosphere is generated by direct UV sunlight, it bulges asymmetrically in the direction towards the sun.