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A4_8 Magnetic Force Field

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Abstract

The aim of this paper was to determine whether a massive charged particle could be deflected using a magnetic field. By considering the force on a charge due to a magnetic field it was found that very high field strength would be necessary to deflect even a single electron, let alone anything with more mass. For this reason magnetic force-fields are not viable for use in protection outside of very acute circumstances, such as from the solar wind. However if the objective is to protect an astronaut performing extra-vehicular activities near the solar wind (an unlikely prospect) it may be useful.

Introduction

Many science-fiction novels and other media incorporate the use of 'force fields' as ways of protecting people or objects. But what are these, and how are they made? It is possible that the 'force' could come from the force generated by an electromagnetic field – which would also provide the 'field'. Magnetic fields act to accelerate charges inside them with a force proportionally tied to their field strength, although this is usually only relevant on a scale as small as individual electrons and protons. This paper discusses whether that effect could be useful on such small charges if they were assigned to larger masses (i.e. a bullet with a very small charge imbalance).

Particles in the solar wind are subject to fairly large magnetic forces and field gradients. It is these forces that lead to the formation of the magnetosphere around Earth, which acts to deflect a large number of particles that would otherwise interact with the planet. Indeed the magnetosphere could be said to be a 'force field' as discussed above, protecting our planet from possibly harmful radiation. The paper determines the energy requirements to recreate the sheathing effect on a much smaller scale appropriate to protecting an astronaut undergoing extra-vehicular activities (EVAs) in regions where ionised particles could be problematic.

Theory

A charged particle moving in a magnetic field experiences a force given by the Lorentz formula [1]

$$\boldsymbol{F} = q(\boldsymbol{v} \times \boldsymbol{B}) \tag{1}$$

where $\boldsymbol{F}$ is the force on the particle, q is the particle's charge, $\boldsymbol{v}$ is the particle speed and $\boldsymbol{B}$ is the field strength experienced. As the force is in the direction of the cross product of the field and velocity it is perpendicular to both of them and as such will act analogously to a the gravitational pull of a large body, causing the particles to 'orbit'. Equating this force to the formula for a centripetal force [2] gives

$$\frac{mv^2}{r_g} = qvB \tag{2}$$

where m is the mass of the particle with charge q and perpendicular velocity component v moving in the field with magnitude B. The equation can then be rearranged to give the resulting 'gyro-radius' r_g when the other variables are defined.

Rearranging for r_g can give the value for the magnetospheric interactions with the solar wind and is interesting on its own, but in this case we will rearrange for B to determine the field strength required to ensure that charged particles gyrate with a radius that we desire.

To create such a magnetic field requires energy, and rather than consider complex geometry it is simpler to assume that the field acts in a sphere with constant magnitude and has a defined edge with zero strength outside. Then we can use the energy density equation for linear non-dispersive metals [3]

$$U = \frac{B^2}{2\mu_0} \qquad (3)$$

where U is the internal energy, and μ_0 is the permeability of free space. Note that to create such a field would not actually be currently physically possible, but it is considered for the purposes of the paper.

Discussion

It is reasonable to want a field that deflects incoming objects to extend 5cm from the person it is designed to protect. That is to say it will have r_g equal to 0.05m, so that the necessary B field can be calculated based on the particle's properties. Also to visualise the situation imagine a person situated at the origin and aligned standing along the y-axis of a Cartesian co-ordinate system. It would be desirable for the magnetic field to then act in an anti-clockwise direction when viewing the person from above (similar to the resulting field if the person was considered to be a wire carrying a charge in the positive y direction – which could even be a way of creating such a field) as this would cause positively charged incoming particles to be accelerated in the negative y direction, meaning protons would head towards the person's feet instead of the head (causing less damage if an impact occurred).

Replacing the variables with those appropriate to an electron in the solar wind (so speeds of 300km^{-1} to 800kms^{-1}, on average 550kms^{-1})[4] and a proton with the same velocity give required field magnitudes of 6.26×10^{-5}T and 0.11T respectively. The energy required to create such fields is determined with equation (3) to be 1.56×10^{-3}J and 4.81×10^{3}J respectively, so they are relatively easy to create.

A charged particle with higher mass is a lot harder to deflect. Considering one with a mass of just 0.02kg travelling at 896ms^{-1} (roughly the mass and speed of a bullet, to give an idea of real world applications – however a bullet would not have the charge of an electron)[6] it is found that a field strength of 2.24×10^{21}T is necessary, which is tremendously large. To put it in context the required energy is 1.996×10^{48}J which is certainly not feasible. In fact some of the strongest magnets have strengths of only 25T. [5]

Conclusion

As shown in the discussion it seems reasonable to create a field strong enough to deflect ionised particles with very low masses, however particles with more mass (macroscopic particles) require very large forces to notably deflect them. As such magnetic force-fields may be useful in situations where particle bombardment needs to be avoided, such as in the solar wind, but currently there is no way to use them to defend against any larger objects. This would involve setting up a strong field (with strength given previously) 5cm away from what you want to protect. Also due to the nature of the field, particles travelling in the y direction will not be deflected, which could be problematic as astronauts may get hit in the head.

References

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