Two Protons Are Released From Rest, With Only The Electrostatic Force Acting. Which Of The Following

Two Protons Are Released From Rest, With Only The Electrostatic Force Acting. Which Of The Following?

When considering the motion of charged particles such as protons, understanding the fundamental forces at play is crucial. In scenarios where two protons are initially at rest and only the electrostatic force acts upon them, various interesting questions arise. These include predicting their acceleration, the energy transformations involved, and their eventual behavior as they repel each other due to their positive charges. This article explores the physics underlying this situation, providing detailed explanations, calculations, and insights into what happens when two protons are released from rest under electrostatic influence.

Understanding the Basic Principles

The Nature of Protons and Electrostatic Force

Protons are subatomic particles with a positive electric charge of approximately +1.602 x 10-19 coulombs. Being positively charged, they repel each other according to Coulomb's Law, which quantifies the electrostatic force between two point charges.

The Coulomb's Law equation is:

$$F = k |q1\ q2| / r2$$

where:

- F is the magnitude of the electrostatic force
- k is Coulomb's constant (~8.988 x 109 Nm2/C2)
- q1 and q2 are the charges of the particles (for protons, both are +1.602 x 10-19 C)
- r is the separation distance between the charges

This force is always repulsive for like charges, meaning the protons push away from each other as soon as they are released.

Initial Conditions and Assumptions

In this hypothetical scenario:

- Both protons start from rest, meaning initial velocities are zero.
- The only force acting on the protons is electrostatic; no external forces or fields are present.
- The initial separation distance is known or specified (commonly denoted as r0).
- The protons are treated as point charges, neglecting quantum effects or other forces such as nuclear forces at larger distances.

Understanding these assumptions simplifies the analysis and allows us to focus solely on electrostatics and classical mechanics.

Physics of the Proton-Proton Interaction

Conservation of Energy

Since only electrostatic forces act, the total mechanical energy of the system is conserved. The initial potential energy associated with the electrostatic interaction will convert into kinetic energy as the protons repel each other and accelerate outward.

The initial potential energy (Uinitial) is:

$$Uinitial = k\ q1\ q2 / r0$$

As they move apart, their potential energy decreases, and their kinetic energy increases:

$$KEtotal = KE1 + KE2$$

Since the protons are identical, they will share the kinetic energy equally due to symmetry.

Calculating the Motion

Given the initial conditions, the key steps to analyze their dynamics include:

1. Determine the initial potential energy based on the initial separation.
2. Apply conservation of energy to find their velocities at any separation.
3. Use Newton’s second law to find acceleration as a function of separation.
4. Calculate the time evolution or the velocity profile as they repel each other.

Step-by-Step Analysis of the Proton Recoil

1. Initial Potential Energy

Suppose the initial separation is r_0. The initial potential energy is:

$$U_0 = \frac{k \times (1.602 \times 10^{-19})^2}{r_0}$$

This energy will be fully converted into kinetic energy when the protons are infinitely far apart.

2. Final Kinetic Energy and Velocities

At an infinite separation, potential energy approaches zero, and all energy is kinetic. Since both protons are identical and start from rest, they will have equal but opposite velocities (v) at any separation r:

- Kinetic energy for each proton:

$$KE = \frac{1}{2} m v^2$$

- Total kinetic energy:

$$KE_{total} = 2 \times \frac{1}{2} m v^2 = m v^2$$

- Energy conservation:

$$U_0 = KE_{total} = m v^2$$

Thus:

$$v = \sqrt{\frac{U_0}{m}}$$

where m is the mass of a proton (~1.673 x 10^{-27} kg).

3. Force and Acceleration as a Function of Separation

The electrostatic force at any separation r is:

$$F(r) = \frac{k \times q^2}{r^2}$$

The acceleration (a) of each proton is:

$$a(r) = \frac{F(r)}{m} = \frac{k \times q^2}{m r^2}$$

This force causes the protons to accelerate away from each other, increasing their separation over time.

Predicting the Motion: Key Calculations

Time Evolution of Separation

Determining how far and how fast the protons move apart involves integrating their acceleration over time, which can be complex. However, energy conservation and the symmetry of the problem allow for simplified calculations.

Approximate approach:

- The relative velocity between the protons at separation r is:

$$v_{rel} = 2 v$$

- The energy relation:

$$\frac{1}{2} \mu v_{rel}^2 = U_0 - U(r)$$

where μ is the reduced mass:

$$\mu = \frac{m}{2}$$

- The potential energy at separation r is:

$$U(r) = \frac{k \times q^2}{r}$$

Therefore:

$$\frac{1}{2} \times \frac{m}{2} \times (2 v)^2 = U_0 - \frac{k q^2}{r}$$

This simplifies to:

$$m v^2 = U_0 - \frac{k q^2}{r}$$

From which we can solve for v at any r.

Implication: As r increases, the kinetic energy increases, and the velocity approaches a maximum value as the particles move far apart.

4. Final State: Infinite Separation

When the protons are very far apart ($r \to \infty$), potential energy tends to zero, and all the initial potential energy is converted into kinetic energy:

$$\text{Total kinetic energy} = U_0$$

Each proton has:

$$v_{max} = \sqrt{\frac{2 U_0}{m}}$$

This maximum velocity depends on their initial separation.

Implications and Real-World Context

Limitations of the Classical Model

While the classical electrostatic model provides insights into the behavior of two protons repelling each other, it is essential to recognize its limitations:

- Quantum effects are significant at very small scales, especially in nuclear physics.
- Nuclear forces become relevant when protons are very close, which can alter their interactions.
- Relativistic effects are negligible at low velocities but become important as velocities approach the speed of light.

Applications in Physics and Engineering

Understanding the electrostatic repulsion of protons has practical significance in various fields:

- Particle accelerators: Designing devices like cyclotrons involves managing electrostatic forces between charged particles.
- Nuclear physics: Proton-proton interactions underpin nuclear fusion processes and the stability of atomic nuclei.
- Electrostatics in engineering: Managing charge distributions and preventing unwanted discharges relies on understanding Coulomb forces.

Summary of Key Takeaways

- When two protons are released from rest under only electrostatic forces, they repel each other, converting potential energy into kinetic energy.
- The initial potential energy depends on the initial separation distance, according to Coulomb’s Law.

Frequently Asked Questions

What happens to two protons released from rest under only electrostatic forces?

They accelerate towards each other due to the Coulomb repulsion, eventually moving closer and gaining kinetic energy.

Will the two protons ever collide if only electrostatic forces are acting?

No, because like charges repel each other, preventing them from colliding unless other forces or quantum effects come into play.

How does the initial potential energy relate to the kinetic energy of the protons during their motion?

As they repel each other, potential energy decreases while kinetic energy increases, conserving total energy in the system.

What is the significance of Coulomb's law in analyzing the motion of two protons released from rest?

Coulomb's law describes the electrostatic force between the protons, which determines their acceleration and trajectory.

Does the electrostatic force cause the protons to accelerate or decelerate as they move apart?

The electrostatic force causes the protons to repel each other, resulting in acceleration away from each other once they start moving.

What energy considerations are involved when two protons are released from rest and only electrostatic forces act?

The initial electric potential energy is converted into kinetic energy as the protons repel and move apart.

If the protons are initially at rest, what is their initial total energy in the system?

Their initial total energy is purely electrostatic potential energy, since their initial kinetic energy is zero.

Additional Resources

Electrostatic Repulsion Between Two Protons: An In-Depth Analysis

Understanding the behavior of two protons released from rest solely under electrostatic forces is a fundamental problem in physics, touching upon classical electromagnetism, nuclear physics, and the principles governing particle interactions. This scenario provides a rich context to explore Coulomb's law, conservation principles, and the subtleties of particle motion at subatomic scales. In this comprehensive review, we delve into the mechanics of the problem, analyze the forces at play, and interpret the physical implications.

Introduction to the Scenario

Imagine two protons initially at rest, separated by some distance r_0, with no external forces acting upon them except their mutual electrostatic repulsion. The question at hand is: What occurs as they begin to move apart under their mutual Coulombic force? How do their velocities evolve over time? What are the energy considerations? And, more broadly, what physical principles govern their motion?

This scenario exemplifies a classical two-body problem under electrostatics, which, despite its simplicity, encapsulates many core ideas in physics. It also serves as an instructive model for understanding nuclear interactions, particle accelerators, and the fundamental nature of electrostatic forces.

Fundamental Concepts and Principles

Coulomb's Law

At the heart of the problem is Coulomb's law, which states that the electrostatic force F between two point charges q_1 and q_2 separated by a distance r is given by:

$$
F = \frac{k_e |q_1 q_2|}{r^2}
$$

where:

- $k_e = \frac{1}{4\pi \varepsilon_0} \approx 8.988 \times 10^9\, \mathrm{Nm^2/C^2}$ is Coulomb's constant.

- q_1, q_2 are the charges; for protons, each has charge $q = +e \approx 1.602 \times 10^{-19}$

\,\mathrm{C} \).

- The force is repulsive, acting along the line connecting the two protons, pushing them apart.

Initial Conditions and Assumptions

- Both protons are initially at rest, meaning their initial velocities \(v_{1,0} = v_{2,0} = 0 \).

- The only interaction considered is electrostatic; other forces such as magnetic effects or nuclear forces are neglected.

- The system is isolated, conserving total energy and momentum.

- The initial separation \(r_0 \) is finite and known.

- Both protons are treated as point particles, neglecting their finite size, which is valid at large enough distances.

Analyzing the Motion: Dynamics of Two Protons

Symmetry and Simplification

Given the identical charges and masses, the problem exhibits symmetry:

- Both protons experience equal and opposite forces.

- They will accelerate away from each other with equal magnitudes of velocity but in opposite directions.

This symmetry simplifies the analysis, allowing us to focus on one proton's motion and infer the other's behavior.

Conservation of Momentum

Since no external forces act, the total momentum remains zero:

\[

\vec{p}_\text{total} = \vec{p}_1 + \vec{p}_2 = 0
\]

Given initial velocities are zero, the system's initial momentum is zero. As the protons repel each other, their momenta develop such that:

\[
m v_1 = m v_2
\]

but in opposite directions, ensuring:

\[
m v_1 + m v_2 = 0
\]

which simplifies to:

\[
v_2 = -v_1
\]

This symmetry allows us to analyze just one proton's motion to understand the entire system.

Energy Conservation

The total mechanical energy \(E \) of the system is conserved:

\[
E = \text{Kinetic Energy} + \text{Potential Energy}
\]

At any instant,

\[
E = 2 \times \frac{1}{2} m v^2 + \frac{k_e e^2}{r}
\]

Initially, at \(r = r_0 \), the protons are at rest, so:

\[
E_\text{initial} = \frac{k_e e^2}{r_0}
\]

As they repel, the potential energy decreases while kinetic energy increases, conserving the total energy.

Deriving the Motion Equations

Reduced Mass Approach

For two-body problems, it is often convenient to switch to the relative coordinate $r = r_2 - r_1$. The motion reduces to a single particle of reduced mass μ:

$$
\mu = \frac{m_1 m_2}{m_1 + m_2}
$$

Since both protons have the same mass m:

$$
\mu = \frac{m \times m}{2m} = \frac{m}{2}
$$

The equation of motion for $r(t)$ becomes:

$$
\mu \frac{d^2 r}{dt^2} = \frac{k_e e^2}{r^2}
$$

or,

$$
\frac{d^2 r}{dt^2} = \frac{2k_e e^2}{m r^2}
$$

This differential equation governs the evolution of the separation $r(t)$.

Energy Equation in Terms of r

Expressing kinetic energy in terms of $r(t)$:

$$
\frac{1}{2} \mu v^2 = \frac{k_e e^2}{r_0} - \frac{k_e e^2}{r}
$$

where $v = dr/dt$.

Rearranged:

$$
v = \frac{dr}{dt} = \sqrt{\frac{2}{\mu}\left(\frac{k_e e^2}{r_0} - \frac{k_e e^2}{r}\right)}
$$

This relation allows us to compute how r varies with time by integrating:

$$
t = \int_{r_0}^{r} \frac{dr'}{v(r')}
$$

Physical Insights and Key Results

Velocity as a Function of Separation

From energy conservation:

$$
\frac{1}{2} m v^2 = \frac{k_e e^2}{r} - \frac{k_e e^2}{r_0}
$$

which leads to:

$$
v(r) = \sqrt{\frac{2k_e e^2}{m}\left(\frac{1}{r} - \frac{1}{r_0}\right)}
$$

This expression shows:

- The velocity increases as the separation r grows, approaching a maximum as $r \to \infty$.

- When $r = r_0$, $v=0$; the protons start from rest.

- For large r, the velocity approaches:

$$
v_\infty = \sqrt{\frac{2k_e e^2}{m r_0}}
$$

which is the asymptotic velocity at infinity.

Time Evolution of Separation

Integrating to find $r(t)$:

$$
t = \int_{r_0}^{r} \frac{dr'}{\sqrt{\frac{2k_e e^2}{m}\left(\frac{1}{r'} - \frac{1}{r_0}\right)}}
$$

This integral can be solved analytically or numerically, but its key physical meaning is:

- The time it takes for the protons to reach a particular separation.

- The acceleration is highest at small r, slowing down as r increases.

Implications and Physical Significance

Energy Considerations

- The initial potential energy $U_0 = \frac{k_e e^2}{r_0}$ is converted entirely into kinetic energy as the protons move apart.

- No energy is lost; the process is conservative.

- The velocities can become significant at small initial separations, illustrating the strong repulsive nature of Coulomb forces at short distances.

Limitations of the Classical Model

- At very small distances, quantum effects become non-negligible, especially considering the proton's finite size (~0.84 femtometers) and quantum tunneling.

- The classical Coulomb model predicts infinite acceleration as $r \to 0$, which is non-physical; in reality, nuclear forces dominate at short ranges.

- The model ignores relativistic effects; at high velocities approaching the speed of light, relativistic mechanics must be considered.

Applications and Broader Contexts

- Nuclear Physics: Understanding proton-proton repulsion helps explain nuclear stability, fusion processes, and the Coulomb barrier.

- Particle Accelerators: The principles underpin the design of devices that accelerate particles by overcoming electrostatic repulsion.

- Astrophysics:

Two Protons Are Released From Rest With Only The Electrostatic Force Acting Which Of The Following

Two Protons Are Released From Rest With Only The Electrostatic Force Acting Which Of The Following

Related Articles

- Utilizing Quantitative In Situ Ftir Spectroscopy To Identify Well-coordinated Pt Atoms As The Active
- To Preserve The North Atlantic Fish Stocks, It Is Decided That Only Two Fishing Fleets, One From The
- Viruses Are Usually Measured In Nanometers Instead Of Micrometers, Which Is What Is Used To Note The

Back to Home