

- c) We are to compute the total force acting on the plane by directly integrating over $q^2/2\epsilon_0$.
Let us proceed to compute the force directly:

$$\begin{aligned} F &= \int da \frac{q^2}{2\epsilon_0} = \frac{q^2 d^2}{8\pi^2 \epsilon_0} \int \frac{r dr d\theta}{(r^2 + d^2)^{3/2}} \\ &= \frac{q^2 d^2}{8\pi^2 \epsilon_0} \int_0^{2\pi} d\theta \int_0^\infty \frac{r dr}{(r^2 + d^2)^{3/2}} \\ &= -\frac{q^2 d^2}{16\pi \epsilon_0} \frac{1}{z^2} \Big|_d^\infty \\ &= -\frac{q^2 d^2}{16\pi \epsilon_0 d^3}. \end{aligned}$$

$$\therefore F = -\frac{q^2}{4\pi \epsilon_0} \frac{1}{(2d)^2} \hat{z}.$$

- d) We are to compute the work required to remove the charge from its position to infinity.
By direct computation, we see that the work required is

$$W = - \int_d^\infty F dz = -\frac{q^2}{16\pi \epsilon_0} \int_d^\infty \frac{dz}{z^2} = \frac{q^2}{16\pi \epsilon_0} \frac{1}{z} \Big|_d^\infty = \frac{q^2}{16\pi \epsilon_0 d}.$$

- e) Let us compute the potential energy of the charge-image-charge system and compare this result with that of part (d) above.

From the definition of potential energy, we see that

$$U = \frac{q^2}{8\pi \epsilon_0 d}.$$

This is precisely twice the energy required to pull the charge q to infinity. This is important: the energy is twice that of the isolated system because we also have energy associated with the electric field of the image charge. In the isolated system, there is only the electric field of a single charge. Furthermore, notice that the potential and hence energy of the image charge depends on the charge and position of q . This implies that it is equivalent to consider q moving in a static field produced by q .

- 8.2) Let us consider the problem of a point charge q located inside a hollow, grounded, conducting sphere of inner radius a .

- a) We are to find the potential function describing the field of the sphere.

This problem is significantly easier to deal because in Jackson's text regarding a charge located outside a conducting, grounded sphere, it should be clear that if the charge is located at the point \mathbf{r} , then by axial symmetry, the image charge must be located along the direction of \mathbf{r} at a distance of $r' > a$. If the method of image charges applies, therefore, the potential at a point \mathbf{r} will be given by the sum

$$V(\mathbf{r}) = \frac{q}{4\pi \epsilon_0} \left(\frac{1}{|\mathbf{r} - \mathbf{r}|} + \frac{q'}{|\mathbf{r} - \mathbf{r}'|} \right).$$

Because the sphere is grounded, we must have $V(r) = 0$ for $r = a$. This situation is identical to that required for the situation described in Jackson and therefore we must have that

$$\frac{1}{a} + \frac{q'}{a} = 0 \quad \text{or} \quad \frac{q'}{q} = -\frac{1}{a}.$$

In particular, this implies that

$$V(\mathbf{r}) = \frac{q}{4\pi \epsilon_0} \left(\frac{1}{|\mathbf{r} - \mathbf{r}|} - \frac{1}{a} \frac{a}{|\mathbf{r} - \mathbf{r}'|} \right) = \frac{q}{4\pi \epsilon_0} \left(\frac{1}{|\mathbf{r} - \mathbf{r}|} - \frac{a}{|\mathbf{r} - \mathbf{r}'|} \right).$$

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Table of Contents Physics Past Cxc Papers Questions

1. Understanding the eBook Physics Past Cxc Papers Questions
 - The Rise of Digital Reading Physics Past Cxc Papers Questions
 - Advantages of eBooks Over Traditional Books
2. Identifying Physics Past Cxc Papers Questions
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Physics Past Cxc Papers Questions
 - User-Friendly Interface
4. Exploring eBook Recommendations from Physics Past Cxc Papers Questions
 - Personalized Recommendations
 - Physics Past Cxc Papers Questions User Reviews and Ratings
 - Physics Past Cxc Papers Questions and Bestseller Lists
5. Accessing Physics Past Cxc Papers Questions Free and Paid eBooks

- Physics Past Cxc Papers Questions Public Domain eBooks
 - Physics Past Cxc Papers Questions eBook Subscription Services
 - Physics Past Cxc Papers Questions Budget-Friendly Options
6. Navigating Physics Past Cxc Papers Questions eBook Formats
 - ePub, PDF, MOBI, and More
 - Physics Past Cxc Papers Questions Compatibility with Devices
 - Physics Past Cxc Papers Questions Enhanced eBook Features
 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Physics Past Cxc Papers Questions
 - Highlighting and Note-Taking Physics Past Cxc Papers Questions
 - Interactive Elements Physics Past Cxc Papers Questions
 8. Staying Engaged with Physics Past Cxc Papers Questions
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Physics Past Cxc Papers Questions
 9. Balancing eBooks and Physical Books Physics Past Cxc Papers Questions
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Physics Past Cxc Papers Questions
 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
 11. Cultivating a Reading Routine Physics Past Cxc Papers Questions
 - Setting Reading Goals Physics Past Cxc Papers Questions
 - Carving Out Dedicated Reading Time
 12. Sourcing Reliable Information of Physics Past Cxc Papers Questions
 - Fact-Checking eBook Content of Physics Past Cxc Papers Questions
 - Distinguishing Credible Sources
 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development

- Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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