**Lightning**

*Interactions b/w hail and smaller ice crystals transfer e- to hail. They are heavier and sink to base of cloud.*

- **Ice Crystals**
- **Hail**
- **Lightning path**: about 1 cm in diameter
- **Light**: due to e-’s recombining w/ions
- **Thunder**: shock wave created by rapid heating of air
- **Upward streamers of + ions travels up from ground. Lightning occurs if it meets stepped leader from cloud.**
- **e- run away from cloud base, leaving net + charge on ground under cloud.**
Lethal Strike

- Physiological effects of a direct strike:
  - stops heart
  - paralyzes muscles
  - internal burns

- Heart may restart, but breathing won’t
  - need mouth-to-mouth

- Other types of strikes:
  - Side flash or touching struck object
  - Ground current
  - Dead-end upward streamer
Lightning Rods

- Provide path for current to pass directly to ground without passing through building
  - path of least resistance
- Diffuse charge build-up
- Photo from lightning research center in FL
  - lightning rods may not provide enough protection to homes built on sandy soil
Lightning Safety

- Lightning kills ~100 people per year in US
- Stay inside if possible. Avoid:
  - showers
    - much lower resistance when wet
  - phones (cell phones are ok)
  - any electrical appliances
- If outside,
  - avoid tall objects
  - seek low-lying area
  - duck head, crouch
  - pull feet together, run, hop on one foot (ground current)
  - stay in car - Faraday cage (Note: Saturns are not safe!)
Lightning: Physical Characteristics

- **Voltage**
  - several hundred million volts

- **Current**
  - $10^{20}$ electrons in a fraction of a second
  - ~10 kiloamps

- **So what is a Volt? what is an amp?**
  - Good question. We’ll get to that soon.
Electric Field: The electric field just before a lightning strike points:

1. toward the ground
2. toward the cloud
3. along the ground
<table>
<thead>
<tr>
<th>Source</th>
<th>$E$ (N/C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluorescent lighting tube</td>
<td>10</td>
</tr>
<tr>
<td>Atmosphere (fair weather)</td>
<td>100</td>
</tr>
<tr>
<td>Balloon rubbed on hair</td>
<td>1 000</td>
</tr>
<tr>
<td>Atmosphere (under thundercloud)</td>
<td>10 000</td>
</tr>
<tr>
<td>Photocopier</td>
<td>100 000</td>
</tr>
<tr>
<td>Spark in air</td>
<td>$&gt;3 \times 10^6$</td>
</tr>
<tr>
<td>Near electron in hydrogen atom</td>
<td>$5 \times 10^{11}$</td>
</tr>
</tbody>
</table>
Electric Field is a Vector

- What is the net Electric field at point A?
- What is the net force on a charge Q that is placed at A?

\[ L = 0.5 \text{ cm} \]
\[ Q = 1 \text{ C} \]
Electric Field of a Rectangle

- What is the net Electric field at point A?
- What is the net force on a charge $Q$ that is placed at A?

$L = 0.5 \text{ cm}$
$Q = 1 \text{ C}$
Electric Field of a Triangle

- What is the net Electric field at point A?
- What is the net force on a charge Q that is placed at A?

\[ L = 0.5 \text{ cm} \]
\[ Q = 1 \text{ C} \]
Handling Charge Distributions

1. Find a variable
2. Express charge of bit in terms of this variable
3. Express distance in terms of the variable
4. Find $E$ at point $P$ for the bit
5. Convert sum of $dE$ to integral
Electric field for a “bit” of charge

- Express the electric field of a bit of charge in terms of the bit’s charge

\[ d\vec{E} = \frac{1}{4\pi\varepsilon_0} \frac{dQ}{r_{Pb}^3} \vec{r}_{Pb} \]

- Where \( d\vec{E} \) is the field due to the bit, \( dQ \) is the bit’s charge, and \( r_{Pb} \) is the vector from the bit to point \( P \)
Electric Field of a Line of Charges

- What is the electric field, $\mathbf{E}$, at point P?

- For continuous charge distributions, we need to use calculus.

\[
d\vec{E} = dE \begin{bmatrix} -\sin \theta \cos \phi \\ -\sin \theta \sin \phi \\ \cos \theta \end{bmatrix}
\]
E of Thin Charged Ring

Represent charge in terms of variable

\[ \frac{dQ}{Q} = \frac{ds}{2\pi r} \]

\[ ds = r\,d\phi \]

\[ dQ = Q\frac{d\phi}{2\pi} \]

\[ dE = \frac{k\,dQ}{R^2} = \frac{kQ}{R^2} \frac{d\phi}{2\pi} = \frac{kQ}{2\pi R^2} \, d\phi \]
Symmetry

• Examples
  • Spherical charge distribution
  • Cylindrical charge distribution
  • Spherical Shell
  • Circular Plate

• If the charge remains unchanged by a transformation (such as a rotation), the field will remain the same too.
Spherical shell of charge

- If $P$ is outside the shell,
  \[ \vec{E} = \frac{kQ}{r^2} \hat{r} \]
- If $P$ is inside the shell,
  \[ \vec{E} = 0 \]
Electric Fields and Conductors

Any initial $E$ that is parallel to surface will cause $e^-$ to move until $E$ parallel is zero.

$E$ inside a conductor is zero!!!
Electric Field of Parallel Flat Plates

- The electric field is the addition of the field due to each plate. Each plate contributes
  \[ E = \frac{1}{2} \frac{|\sigma|}{\varepsilon_0} \]

- The electric field of the plates:
  \[ \vec{E} \approx \begin{cases} 
  \frac{|\sigma|}{\varepsilon_0} \hat{n} & \text{at points between the plates} \\
  0 & \text{at points not between the plates} 
\end{cases} \]
Electric Field is a form of Energy

- The electric field is a form of energy
- The energy density of an electric field is given by
  \[ u_E = \frac{1}{2} \varepsilon_0 E^2 \]
- Where \( E \) is the magnitude of the field
- To calculate the total energy in a volume, \( V \)
  \[ U = u_E V = \frac{1}{2} \varepsilon_0 E^2 V \]
Electrical Shielding

(a) 

(b)
Electric Field and Conductors

- Electric field inside a conductor is zero (when charges are at rest)
- Any net charge on a conductor is on the surface
- The electric field is always perpendicular to the outside surface of a conductor.
Motion of q in a uniform E field

The figure shows an electron entering a uniform electric field of 1500. N/C. What is the acceleration of the e\textsuperscript{-} once inside the field?

\[ m_e = 9.11 \times 10^{-31} \text{ kg} \]
\[ q_e = 1.602 \times 10^{-19} \text{ C} \]
Motion of q in a uniform E field

If the electron is initially moving with a horizontal velocity of \(3.0 \times 10^6\) m/s, and \(l = 20\) cm, what is the magnitude and direction of the electron’s velocity as it leaves the parallel plates?

\[
\begin{align*}
m_e &= 9.11 \times 10^{-31}\text{ kg} \\
q_e &= 1.602 \times 10^{-19}\text{ C}
\end{align*}
\]