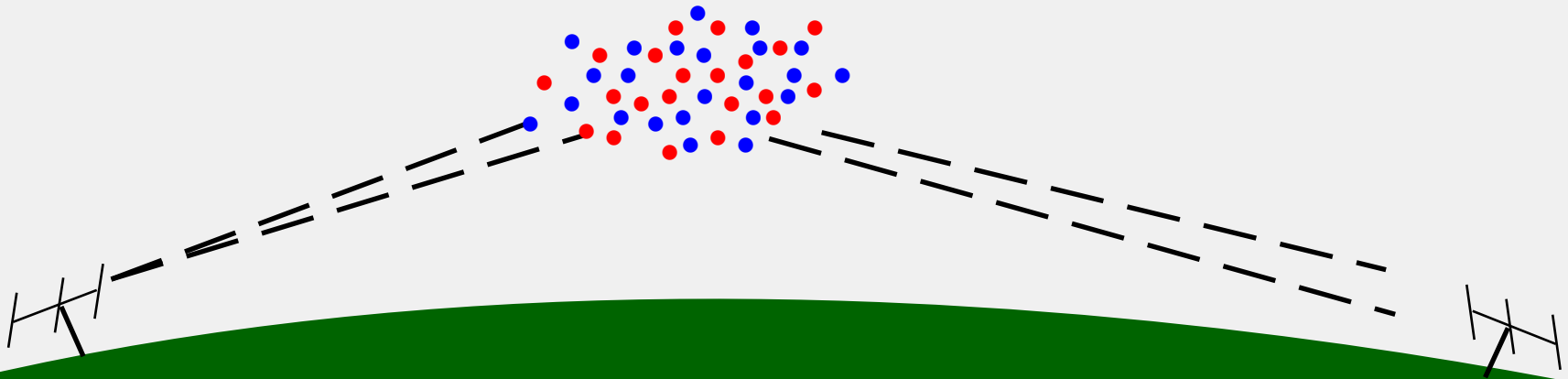


# We Communicate by Ionospheric Reflection ... ... not Refraction



**Mike Hasselbeck WB2FKO**

**Central States VHF Conference July 2024**

**This talk deals exclusively with ionosphere**

**No tropospheric ducting, rain scatter, etc**

**Refraction vs Reflection (Optics and RF are E-M waves)**

**Intuitive model of the ionosphere**

**Ignore secondary magnetic field effects**

**Analysis: 50 MHz vs 144 MHz**

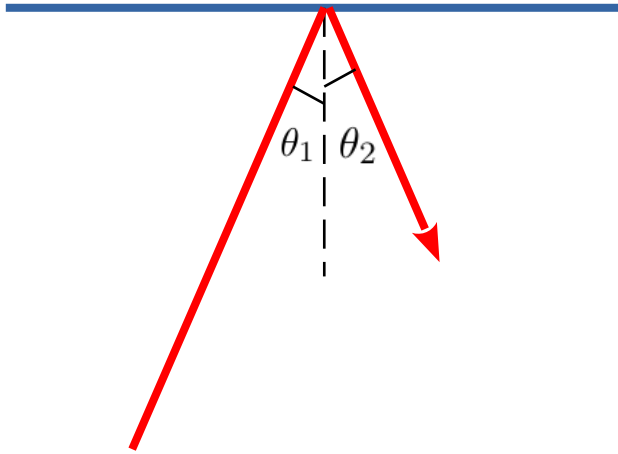
# REFLECTION

Mirror, mirror on the wall...

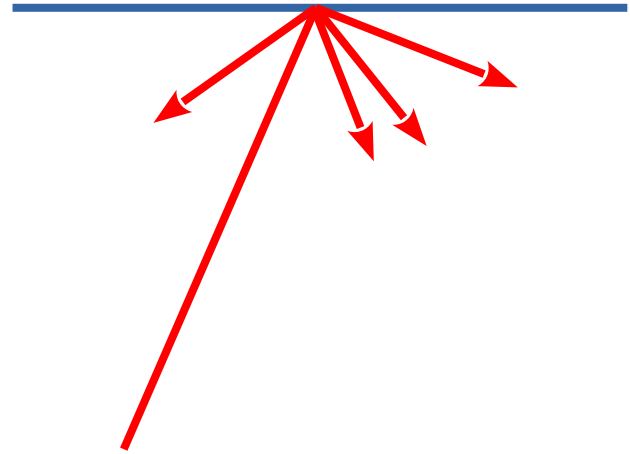


# REFLECTION RAY TRACING

Specular Reflection:  $\theta_1 = \theta_2$



Diffuse Reflection



**REFRACTION:** Deflection in the path of an electromagnetic wave as it passes through different media



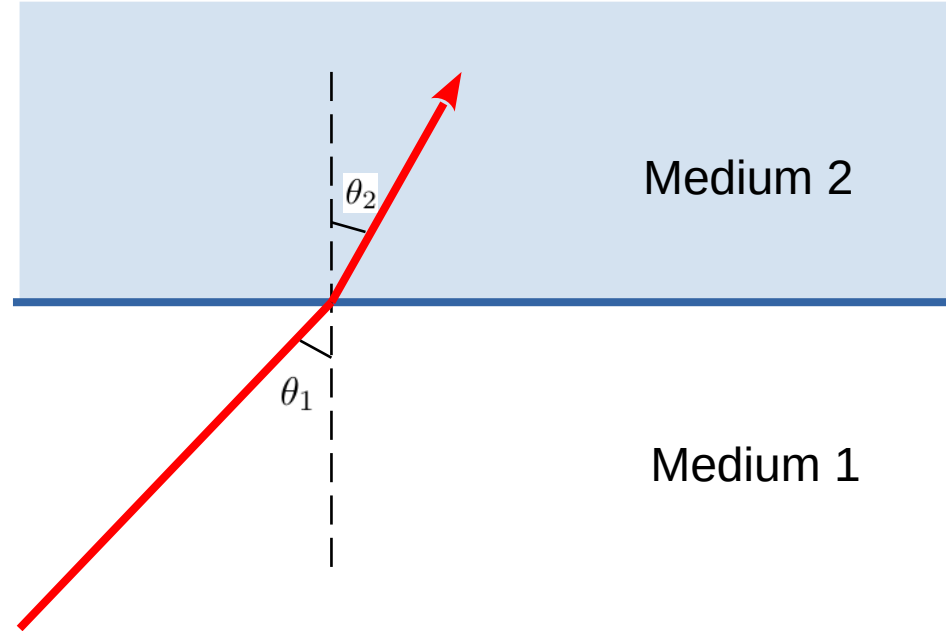
**Index of refraction**

Air: 1.0

Water: 1.33

Glass: 1.5

# REFRACTION RAY TRACING





“Free electrons cause radio waves to slow down, refract, and bend...  
... reflection is really the wrong term.”

The video player shows a presentation slide on the left and a speaker on the right. The slide is titled "Variability of Received Solar Energy Due to the Tilt of the Earth's Axis" and contains the following text: "Increased ionization during the Spring and Fall equinoxes" and "Less frequent and lower intensity geomagnetic storms during the Summer and Winter solstices". The slide also features a diagram of the Earth with the Sun and arrows representing solar radiation. The speaker is a man in a dark shirt, gesturing while speaking. A subtitle at the bottom of the video reads: "so refraction reflection is really the wrong term it". The video player interface includes a progress bar at 34:01 / 1:20:03, a volume icon, a closed captions icon, a settings icon, a full screen icon, and a "FRANK DONOVAN W3LPL SUBSCRIBE" button.

Frank Donovan W3LPL on RF & HF Propagation



FairlawnARC.org  
1.3K subscribers

Subscribe

12



Share

Clip

Save





**“You’re not bouncing off of anything...**

**...the signal encounters a different index of refraction...**

**...refraction bends the signal back down.”**



**Ionospheric Propagation Not Reciprocal (#892)**



**David Casler Ask Dave**  
126K subscribers

Join

Subscribe

266



Share

Thanks



2.8K views 11 months ago Ask Dave! Answers Your Ham Radio Questions





“...the Sky Wave is where you’ve gone up and you’re refracting off the E- and F-layers...”

**HF Propagation Modes**

Three fundamental HF propagation modes:

- Ground wave: vertically polarized local propagation on 160 and 80 meters only
- Surface or space wave: propagation extending somewhat beyond the line of sight
- Sky wave: all propagation via the ionosphere

you've gone up and you're refracting off in the E and the F layers and

**The Ionosphere, Shortwave Radio, and Propagation**



MIT Film & Video Production club  
3.48K subscribers

Subscribe

587



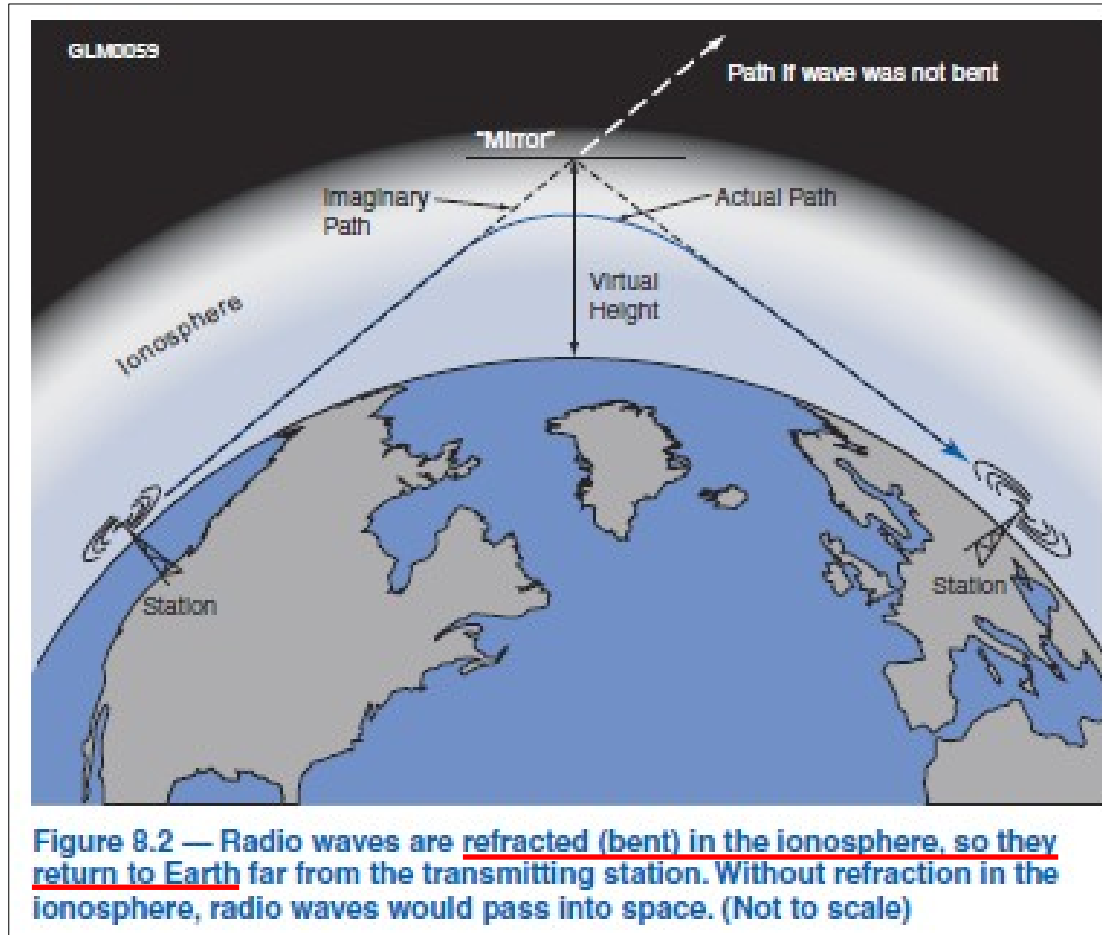
Share

Clip

Save



# ARRL Instructor Resource: General Class License



## From the General Class License Question Pool\*:

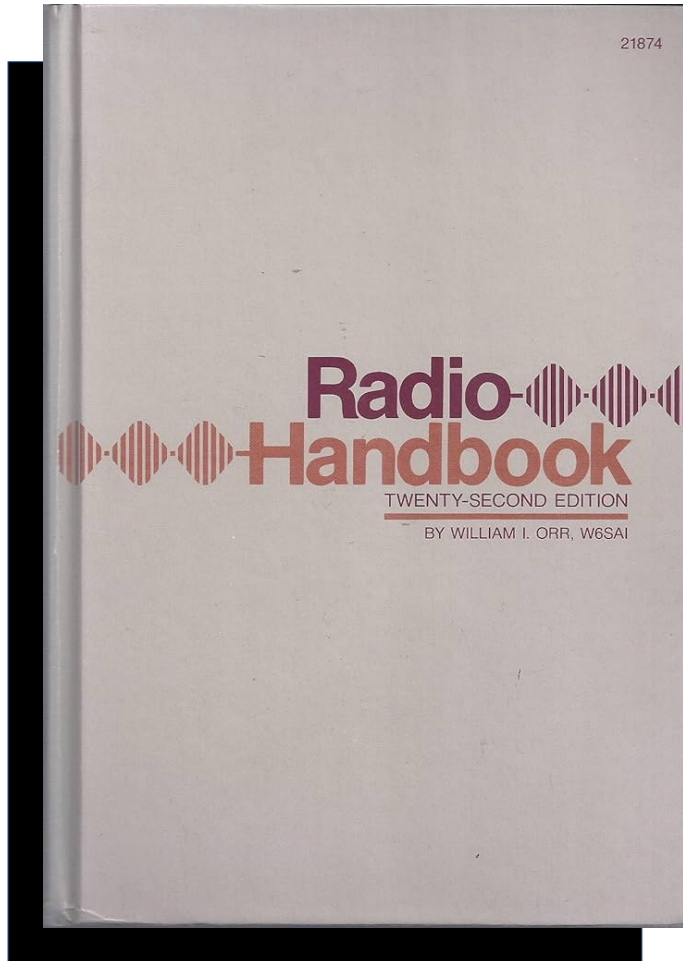
G3C02 (A)

**What is meant by the term “critical frequency” at a given incidence angle?**

- A. The highest frequency which is refracted back to Earth
- B. The lowest frequency which is refracted back to Earth
- C. The frequency at which the signal-to-noise ratio approaches unity
- D. The frequency at which the signal-to-noise ratio is 6 dB

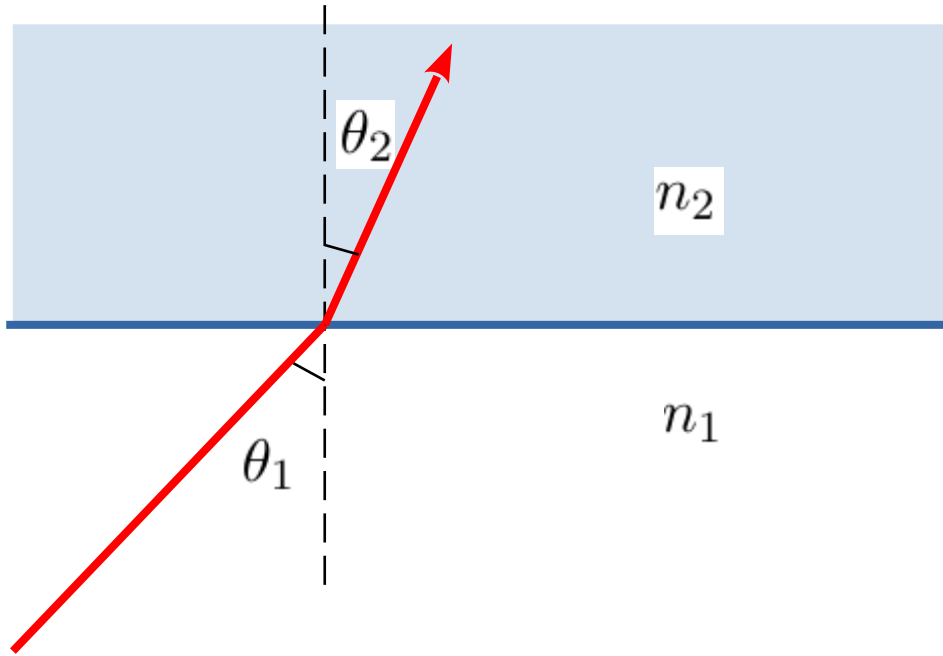
~~

\*<http://www.arrl.org/general-question-pool>



**William Orr, W6SAI:**

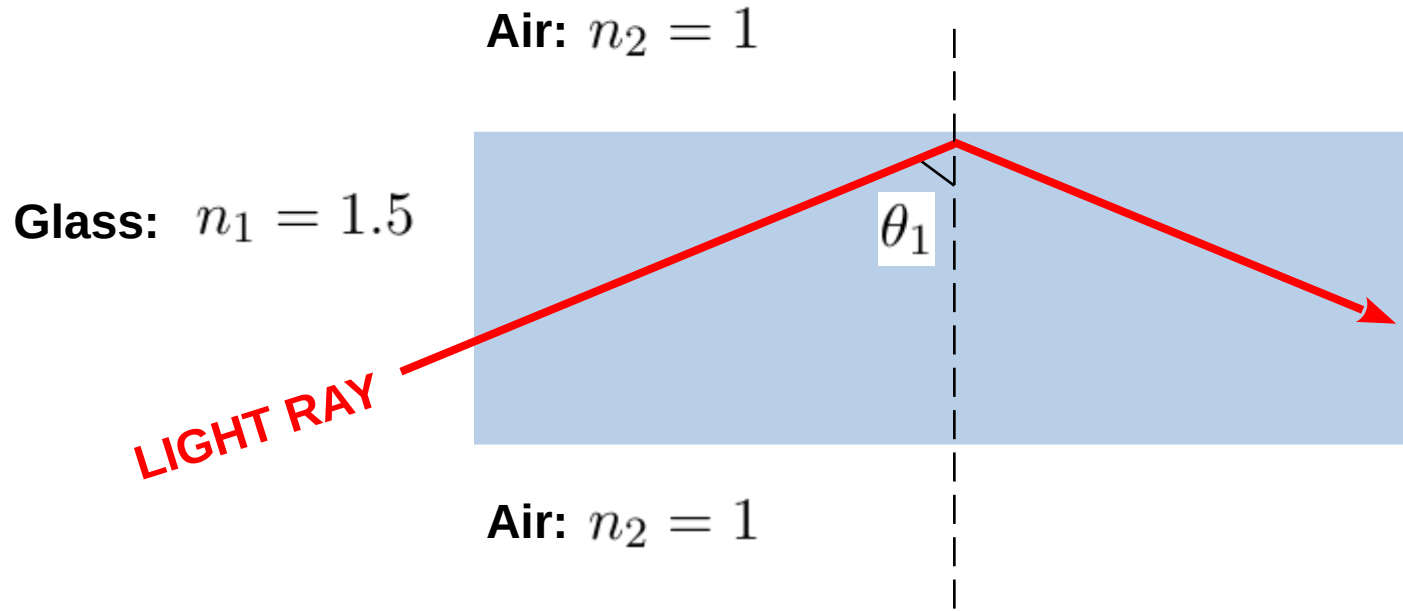
**“Propagation ... is primarily by  
ionospheric reflection.”**



Willebrord Snellius:  
1580--1626

**Snell's Law of Refraction:**  $n_1 \sin \theta_1 = n_2 \sin \theta_2$

# Total Internal Reflection in Glass Fiber

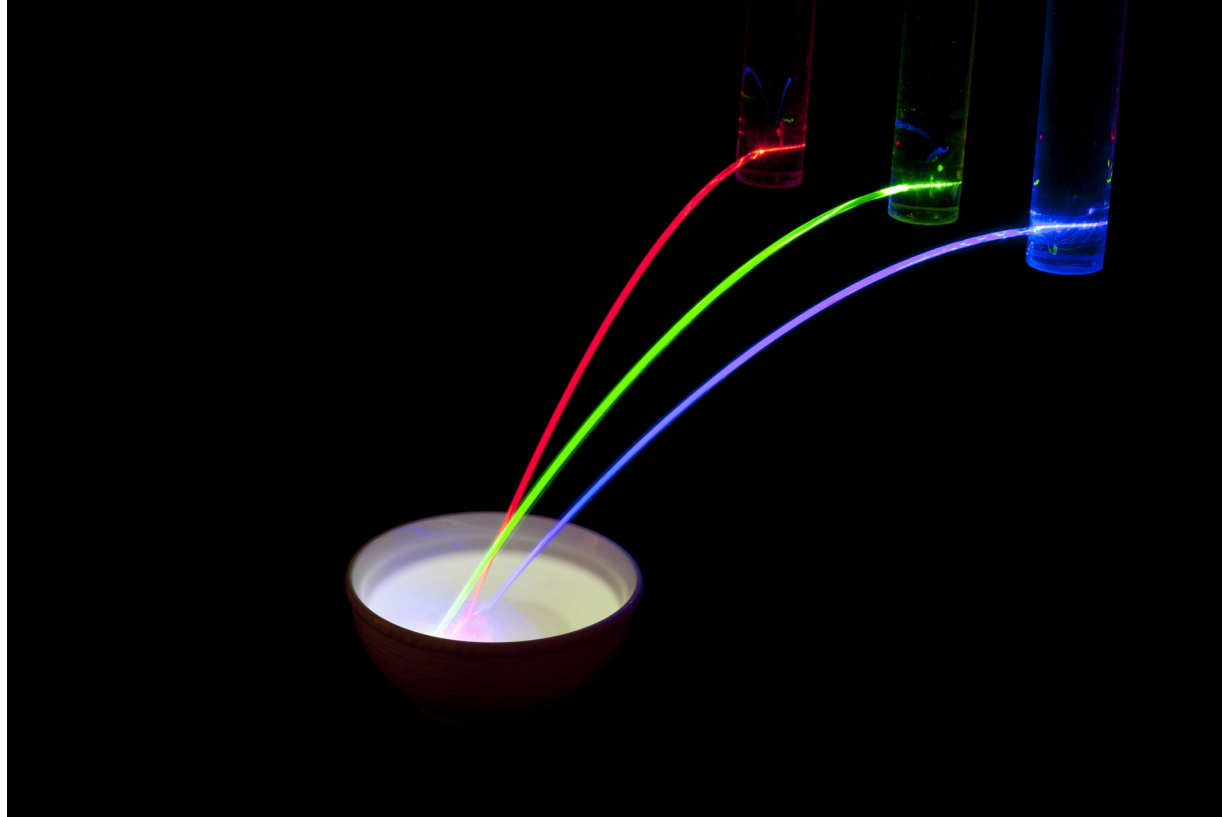


For  $\theta_1 > 41^\circ$  Snell's Law has no solution!

These rays are completely reflected – there is no refraction

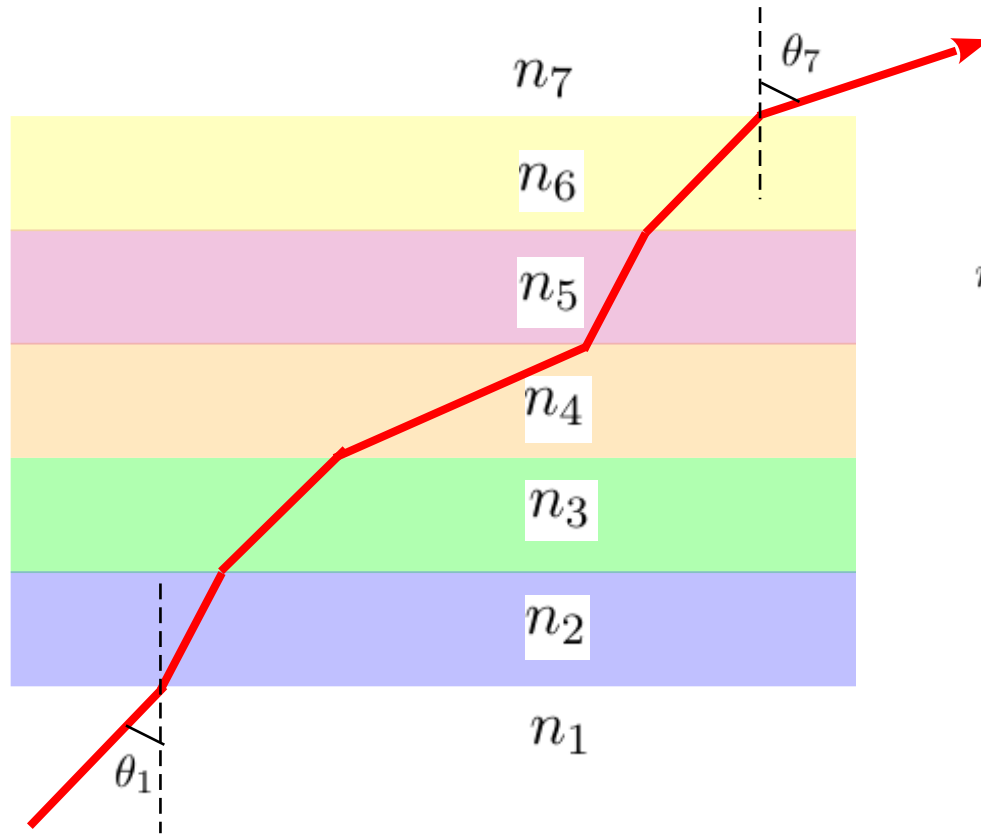
# TOTAL INTERNAL REFLECTION:

Laser light launched into liquid Laminar flow streams



Courtesy of Dr Alexander Albrecht, UNM Physics & Astronomy

# Propagation through stratified layers of ionosphere



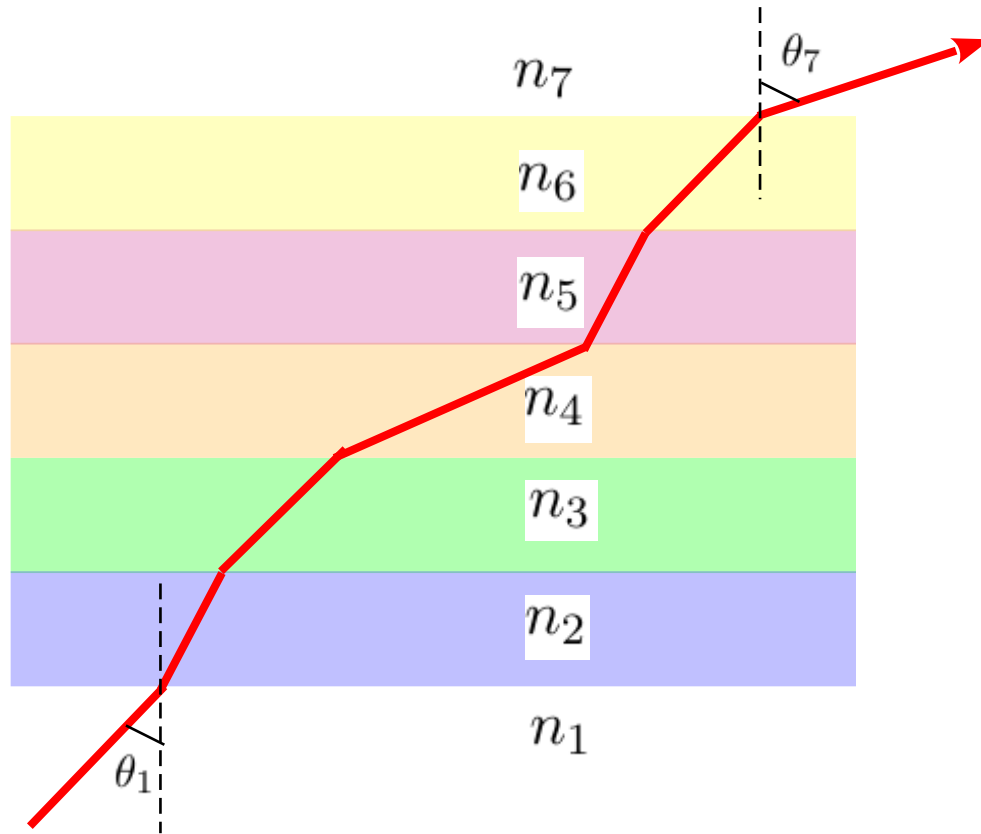
$$n_1 \sin \theta_1 = n_2 \sin \theta_2 = n_3 \sin \theta_3 = \dots = n_7 \sin \theta_7$$

$$n_1 \sin \theta_1 = n_7 \sin \theta_7$$

$$\theta_7 < 90^\circ$$



## Refraction alone cannot return a radio wave back to the earth's surface

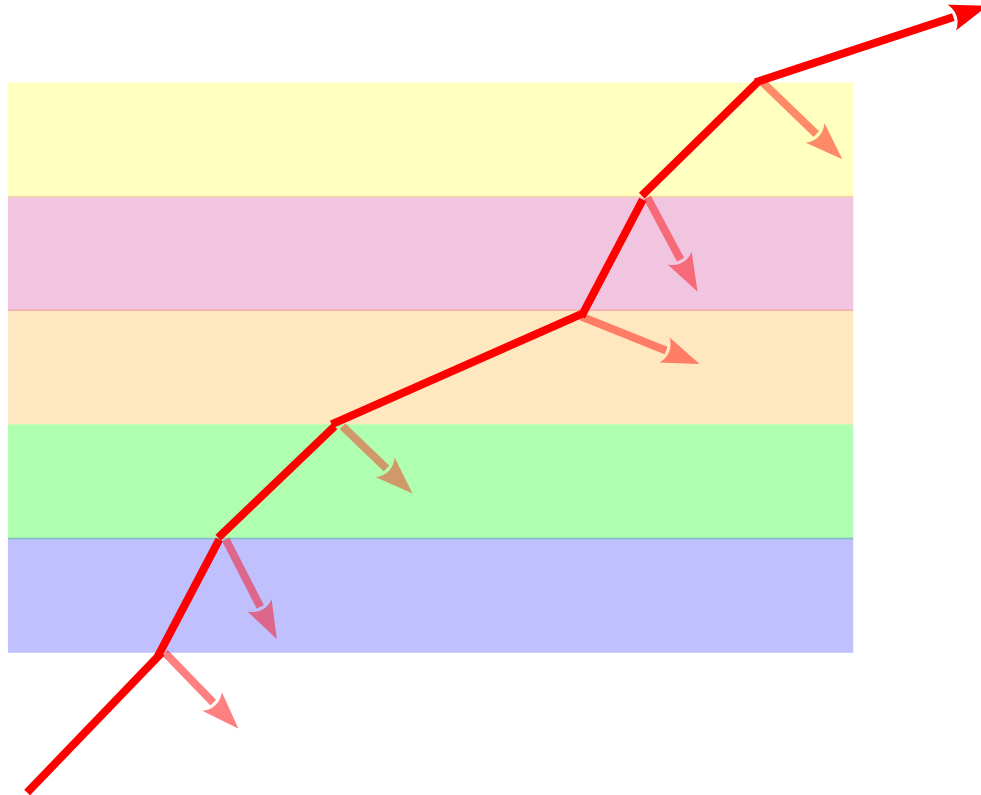


In vertically stratified layers like the **ionosphere**, no amount of refraction can bend an electromagnetic wave beyond 90 degrees.

**Partial reflections** will occur at each interface where there is an index mismatch

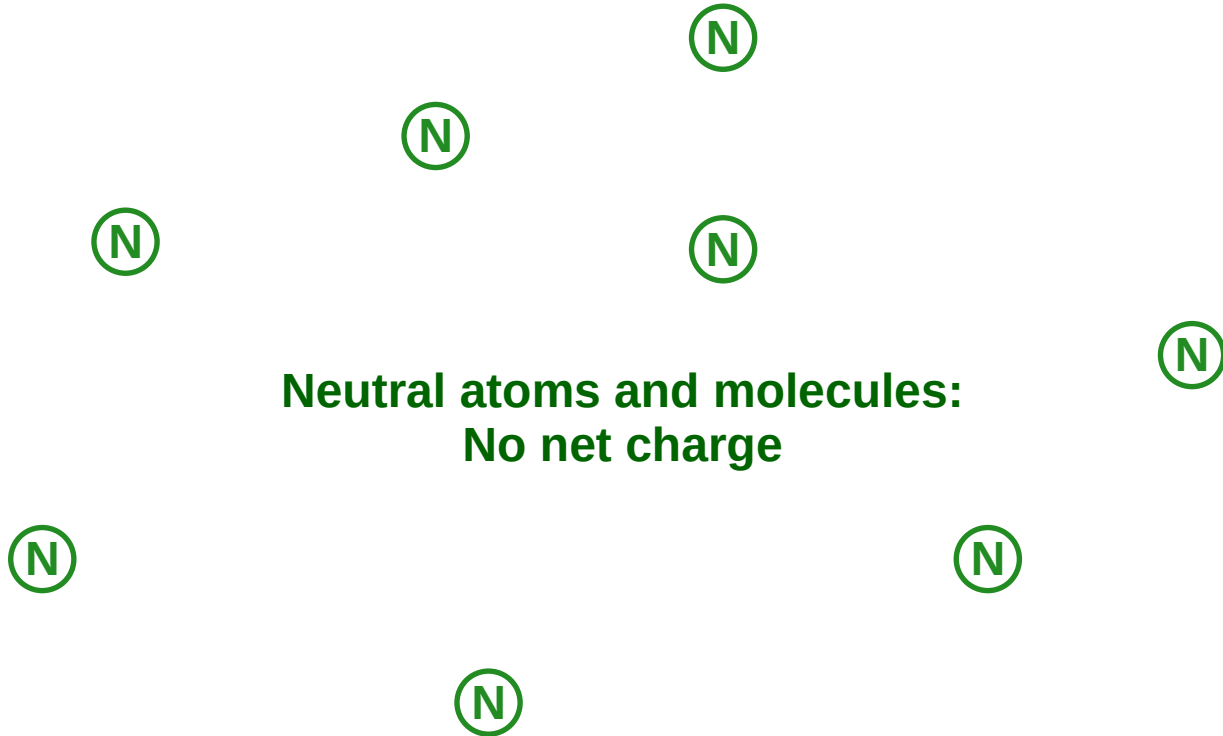


Augustin-Jean Fresnel  
1788-1827

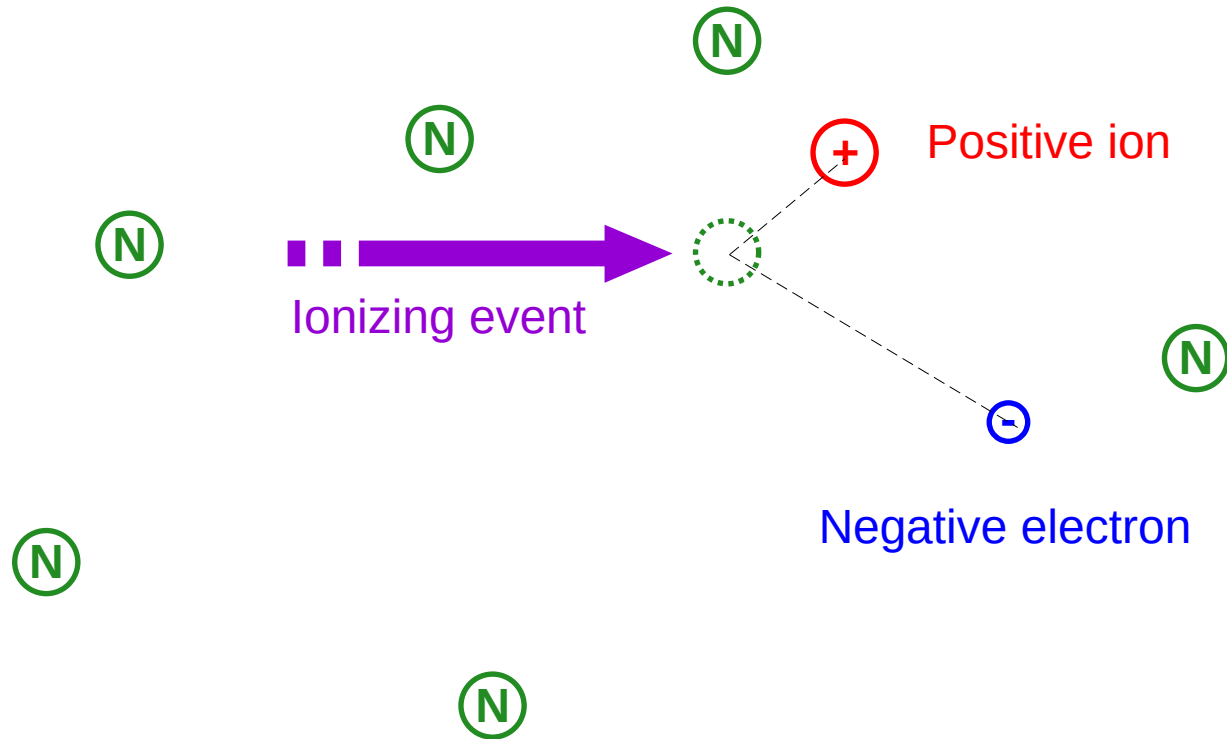


... but Fresnel **reflection** is not the same thing as **refraction**.

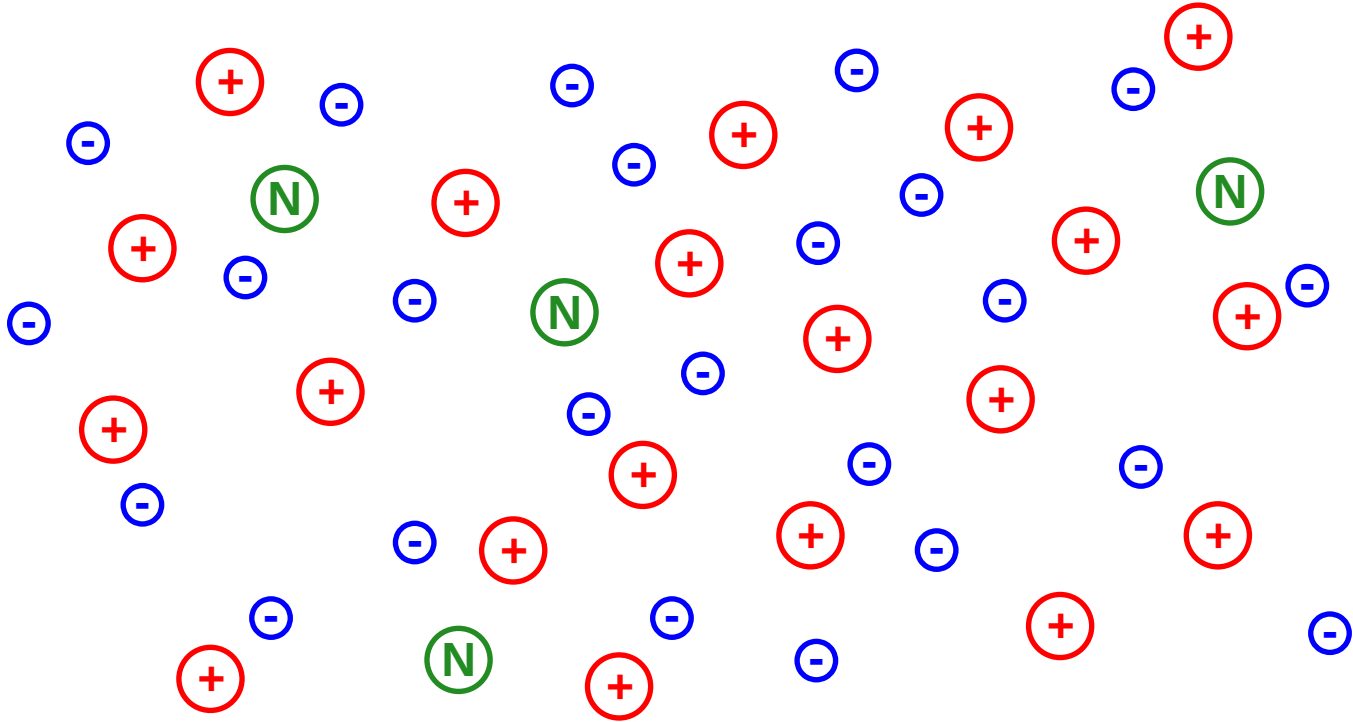
# SIMPLE MODEL OF IONOSPHERE



# SIMPLE MODEL OF IONOSPHERE

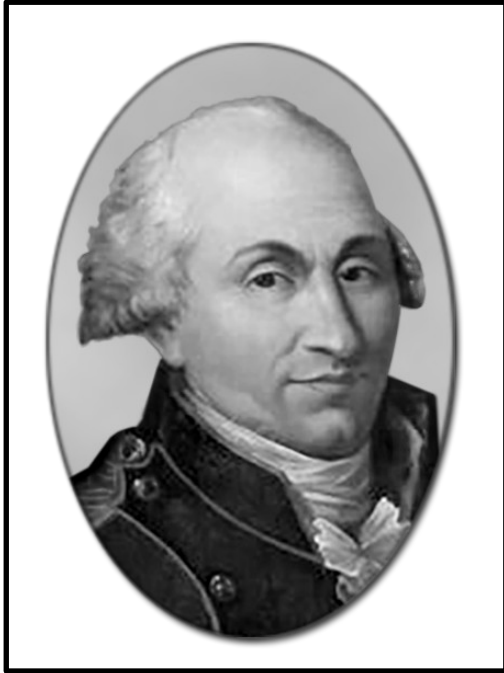


# Equal density of **IONS** and **ELECTRONS**

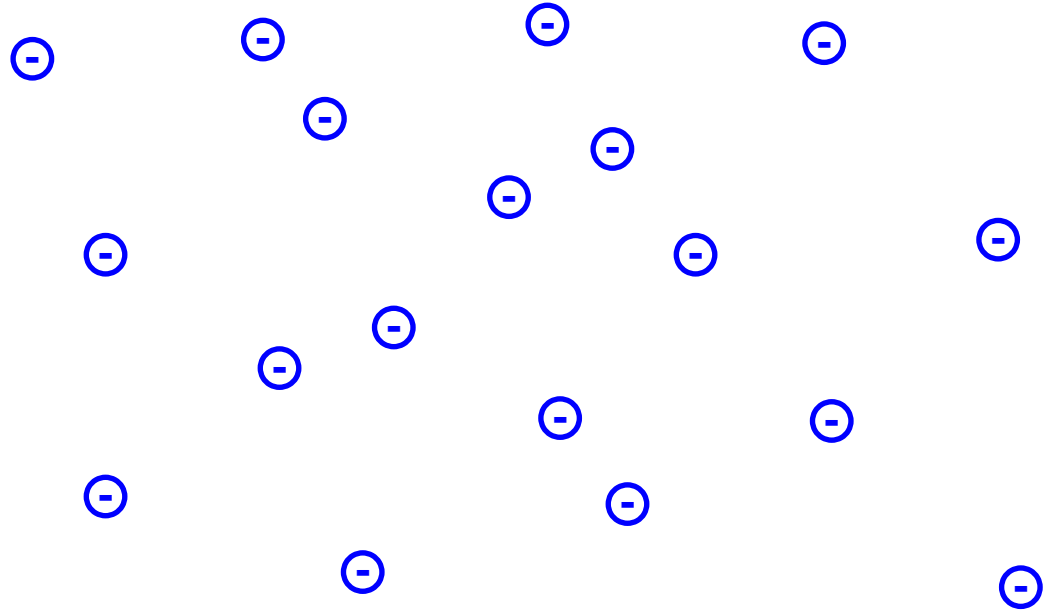


The ensemble is electrostatically neutral: *PLASMA*

# It's not just the **Electrons** – The Crucial Role of **Ions**



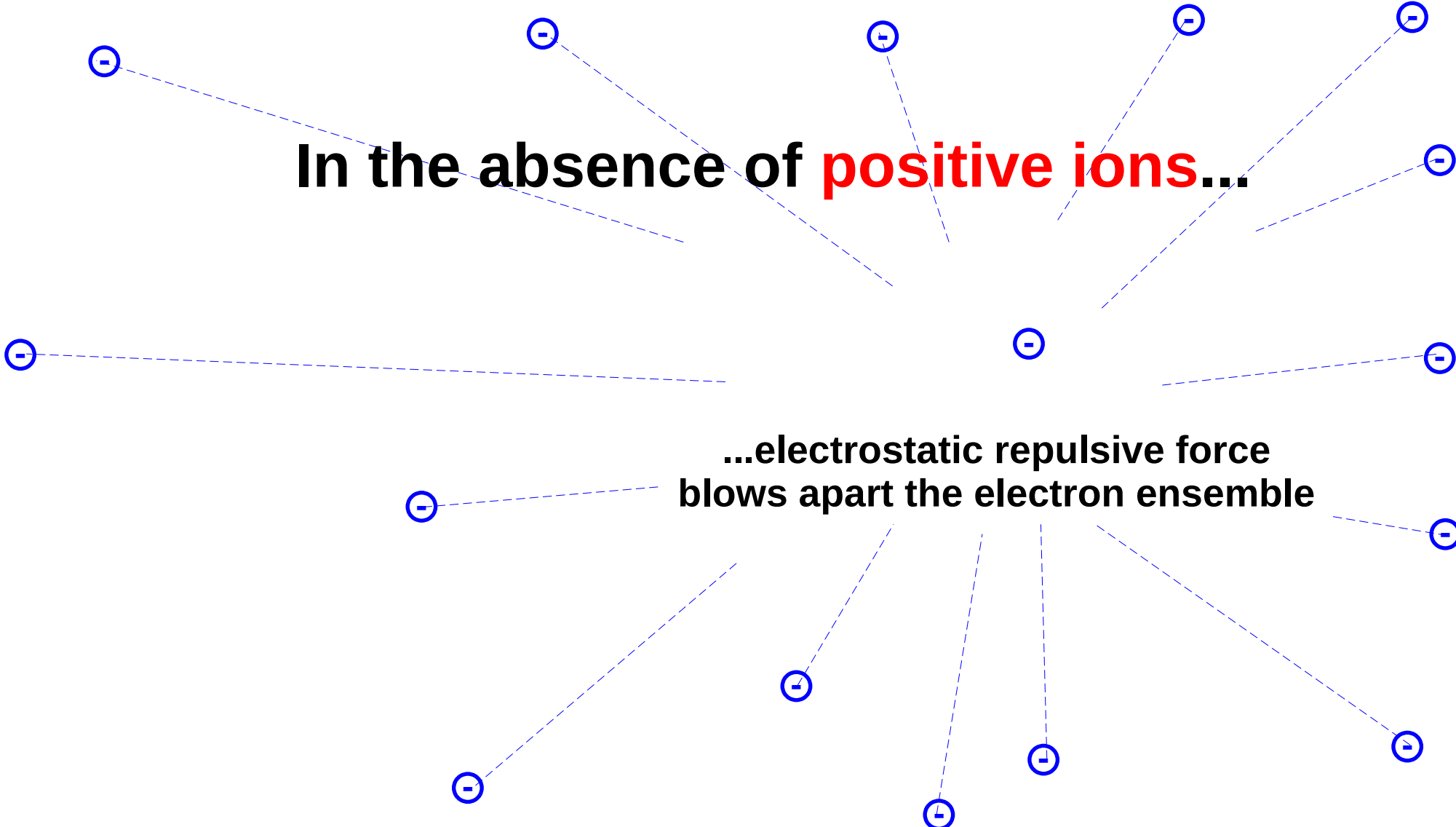
Charles-Augustin de Coulomb  
1736--1806



**Coulomb's Law: Like-Charges Repel**

In the absence of **positive ions...**

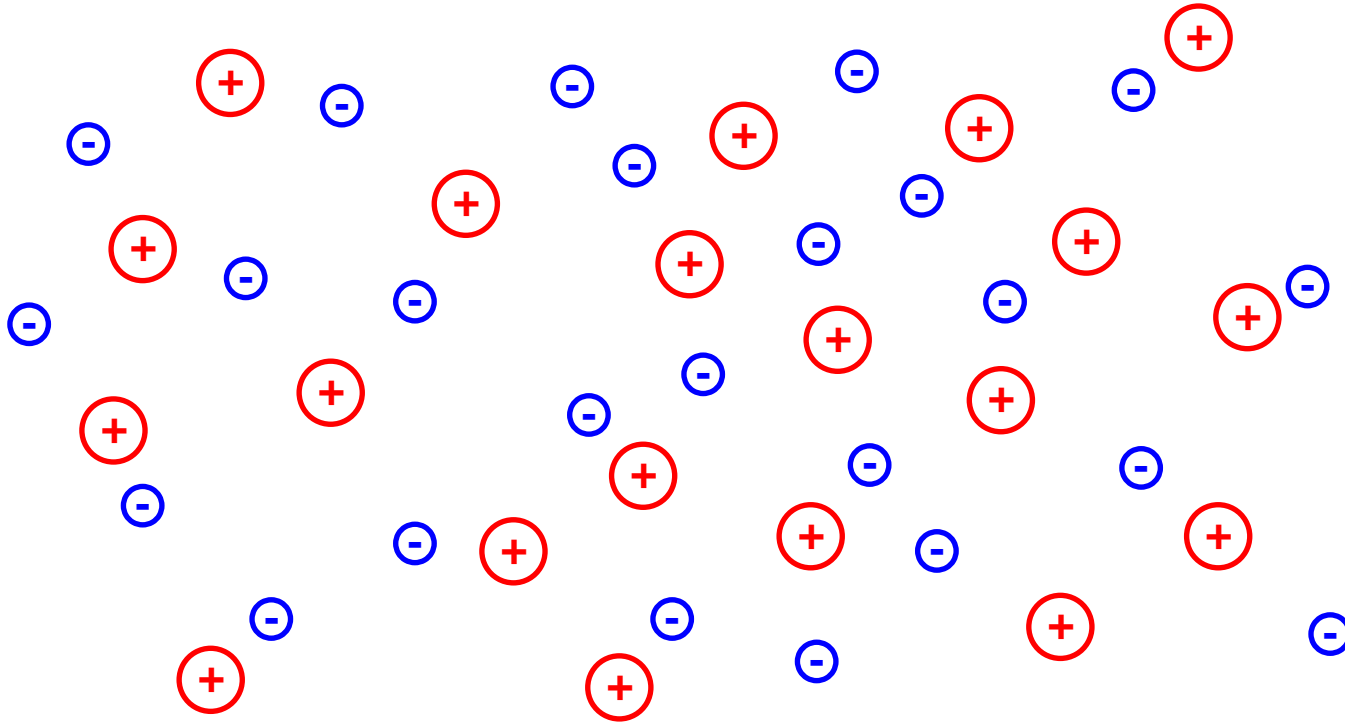
...electrostatic repulsive force  
blows apart the electron ensemble



**IONS:** Heavy, fixed positions

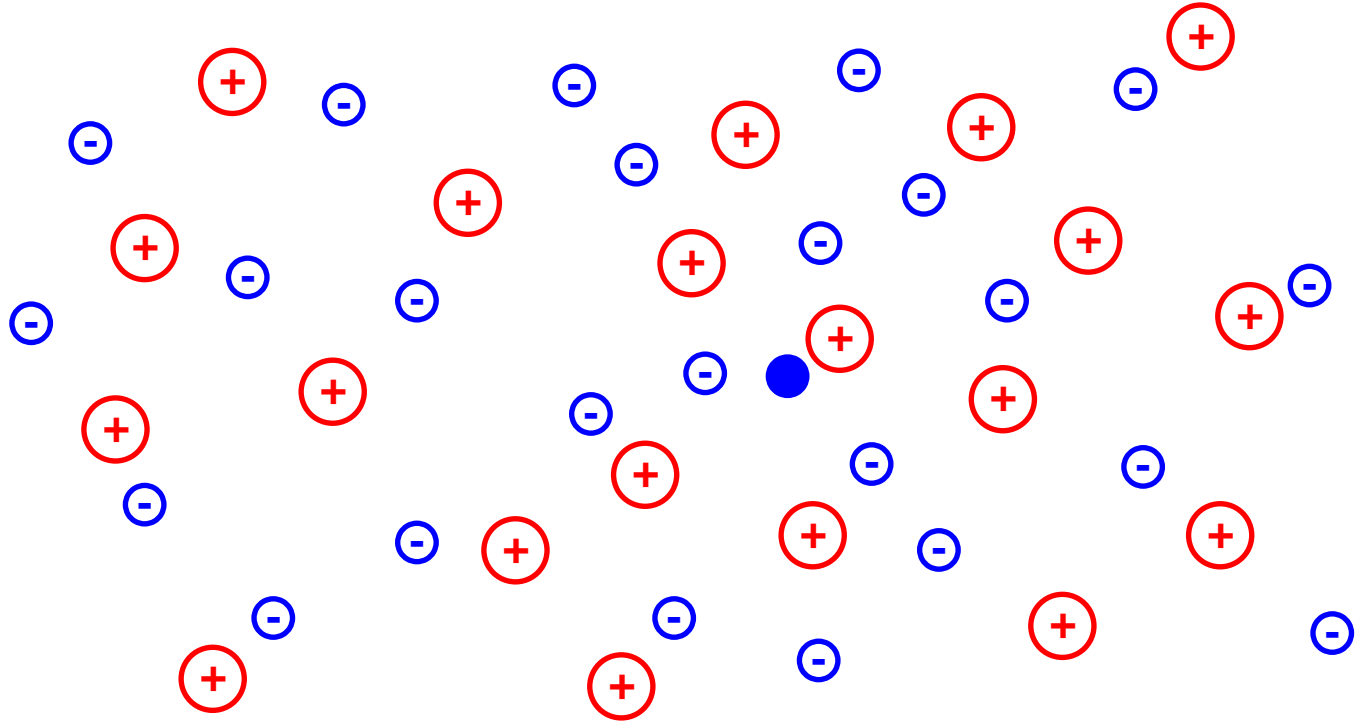
**ELECTRONS:** Light and mobile

**PLASMA:** No net charge; + and - exactly balance



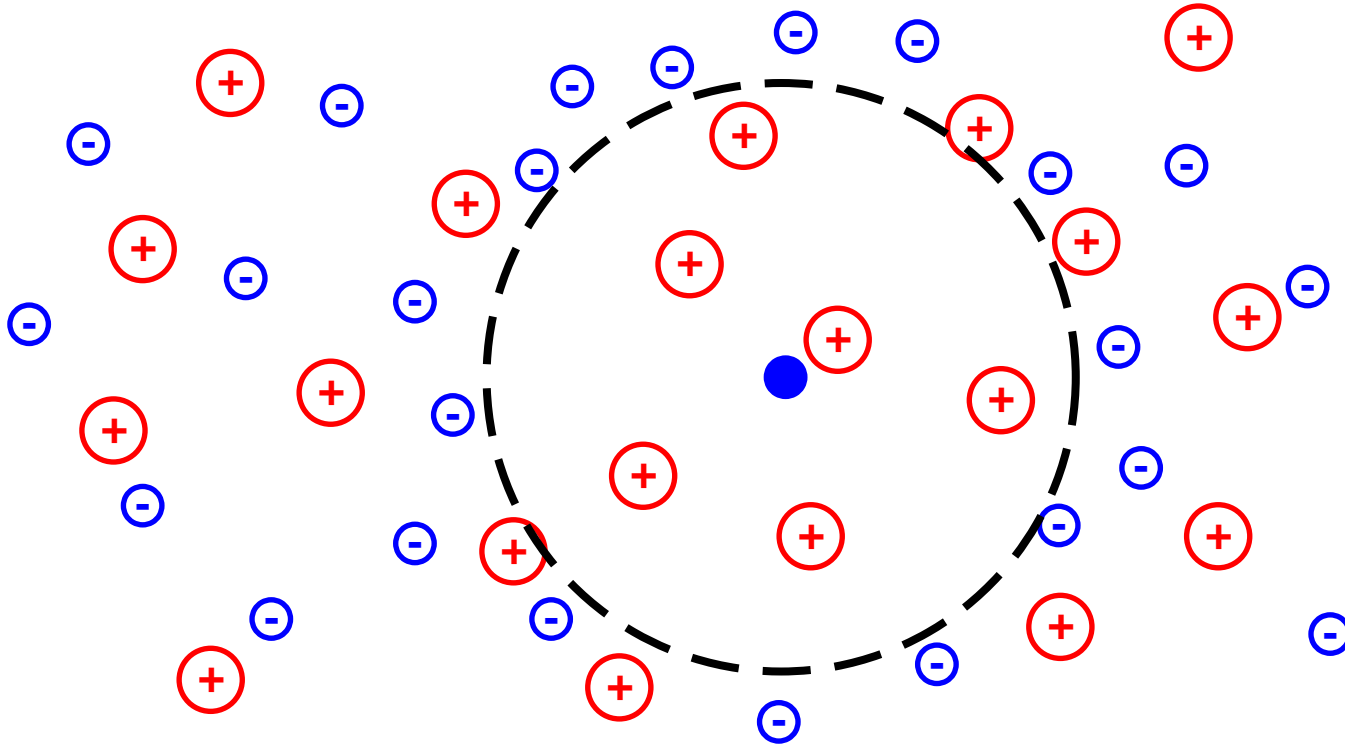


Upset the charge balance by introducing an *extra negative charge*



Plasma does not fly apart

Mobile electrons re-arrange to **screen** electric field of the extra charge



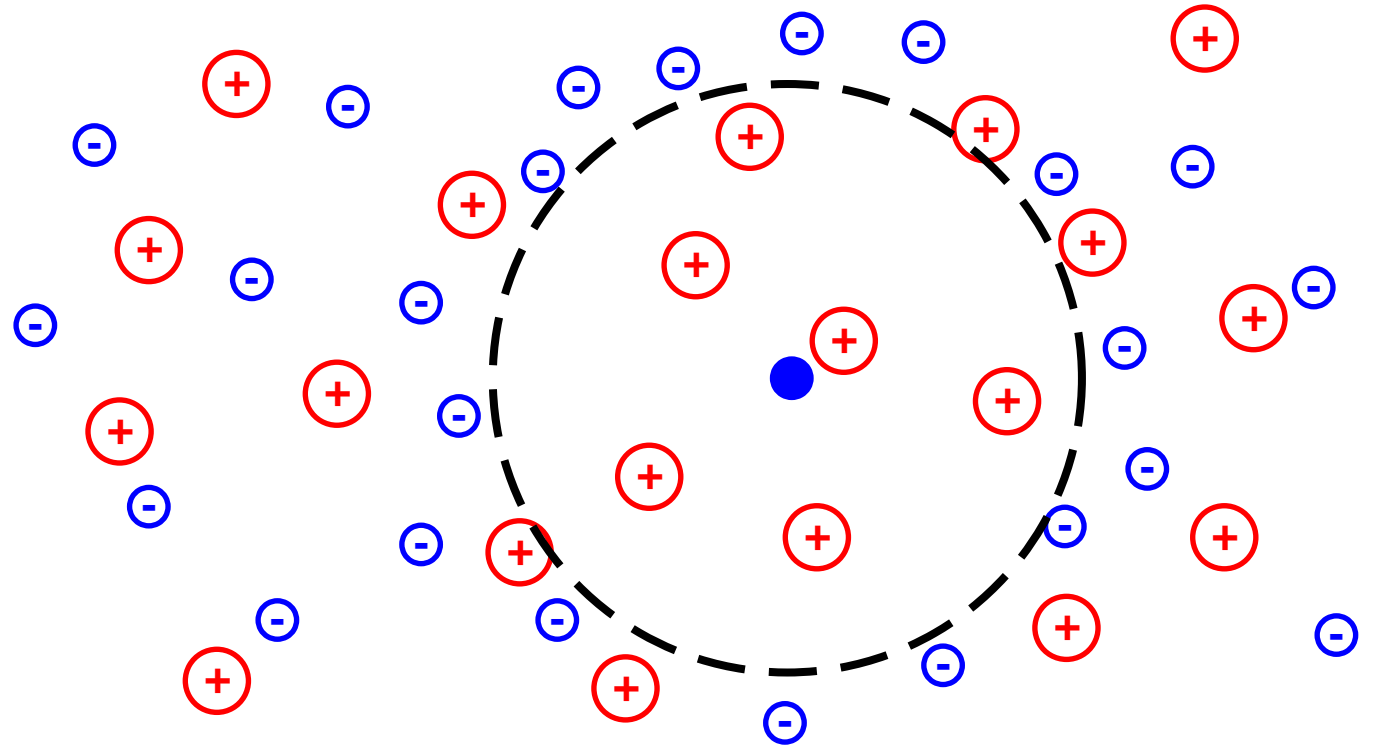
# Debye Screening Radius

Outside the radius, plasma remains electrically neutral

The extra charge is “invisible”



Peter Debye  
1884--1966





Paul Drude  
1863--1906

**Charge screening cannot happen instantly!**

**What are the dynamics, i.e. time response?**

## ***The Drude Model***

# Drude's Model of Plasma Oscillations: Interplay of Two Forces

- Electric Field (Coulomb, Gauss)
- Newton's Second Law of Motion ( $F = ma$ )



C.A. de Coulomb

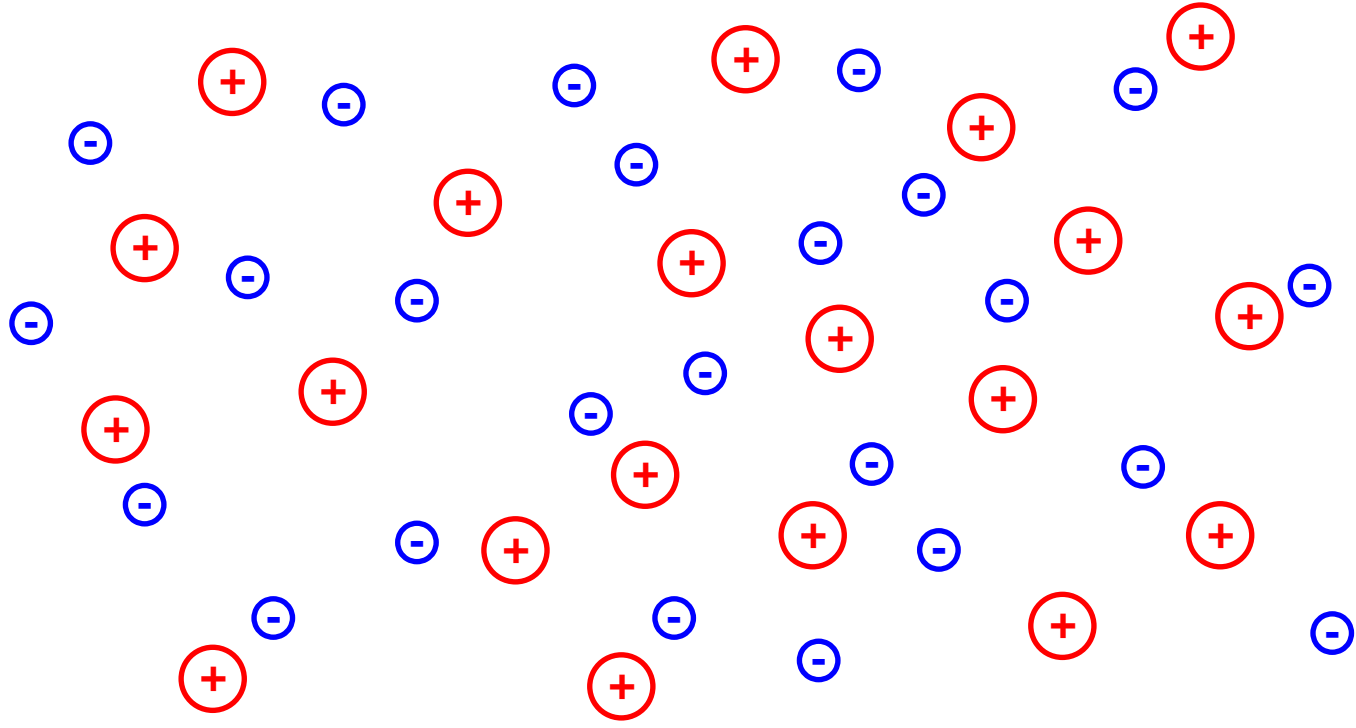


F. Gauss

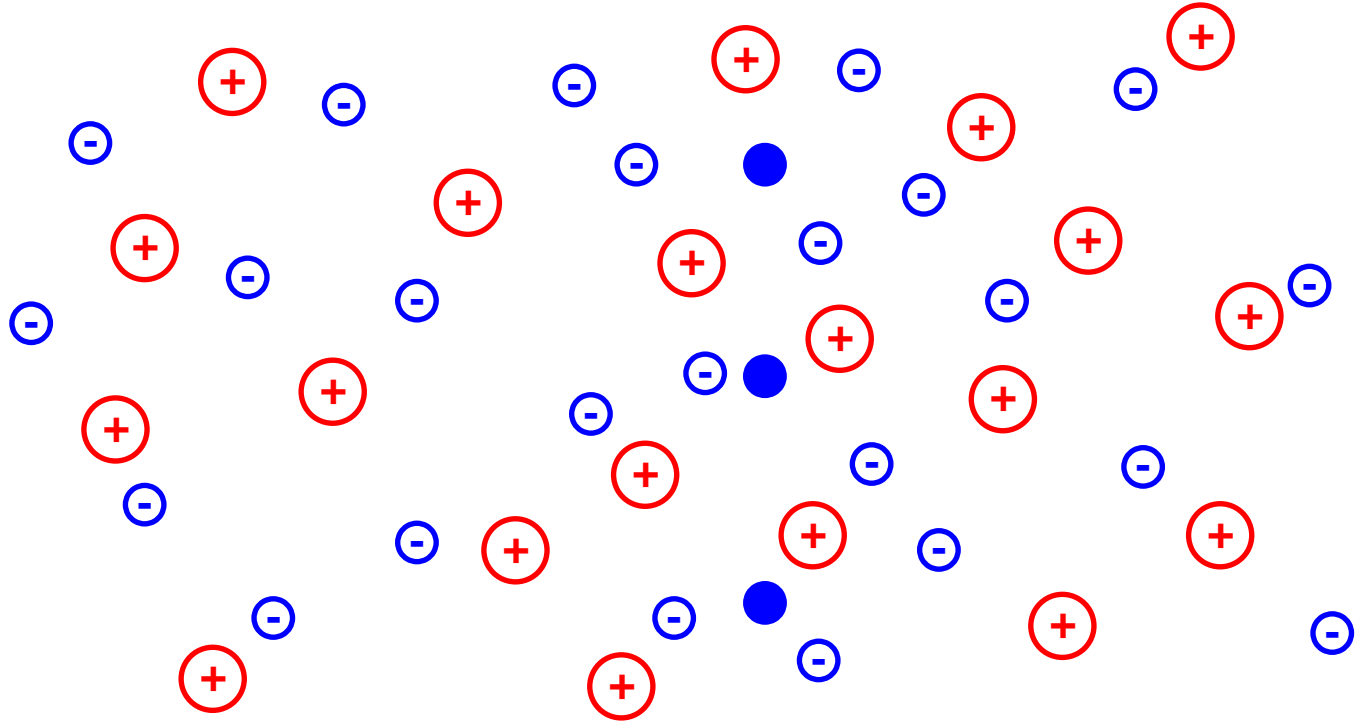


I. Newton

Upset the charge balance by introducing a line of *negative charge*

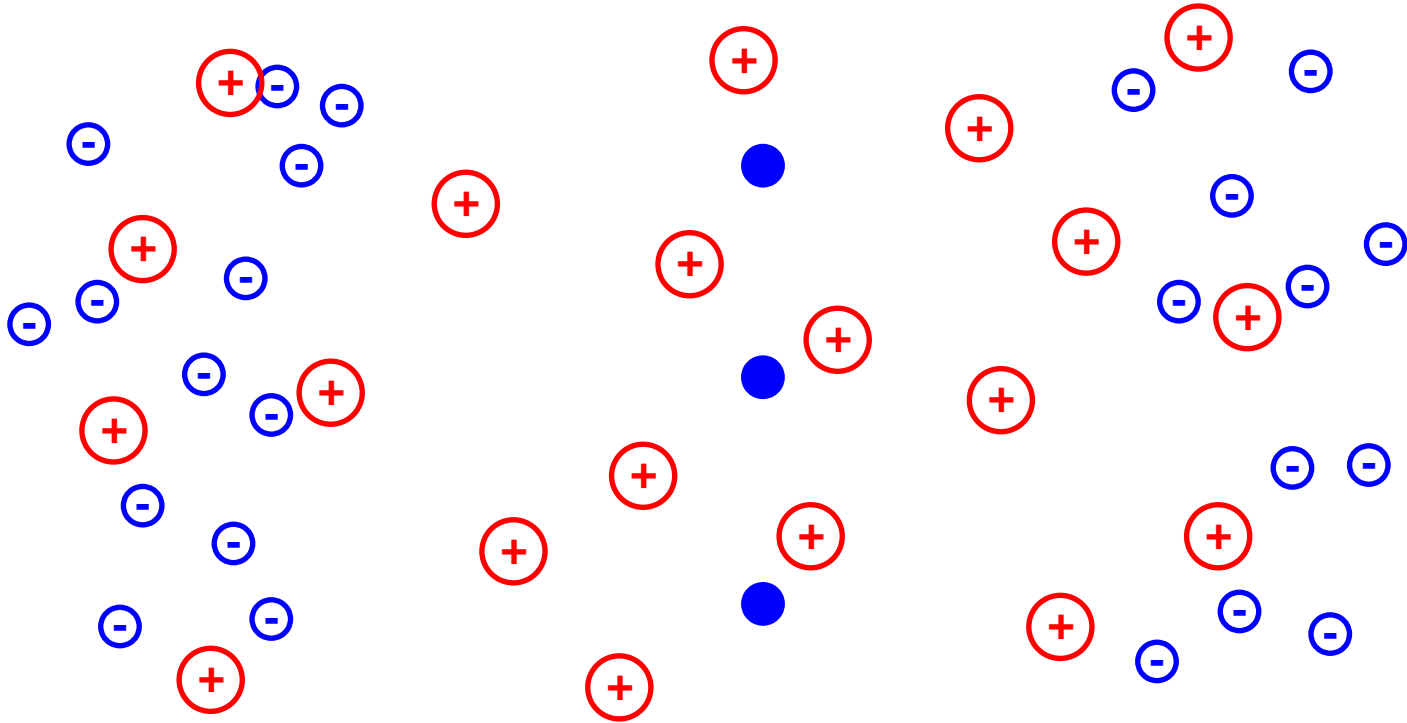


Upset the charge balance by introducing a line of *negative charge*



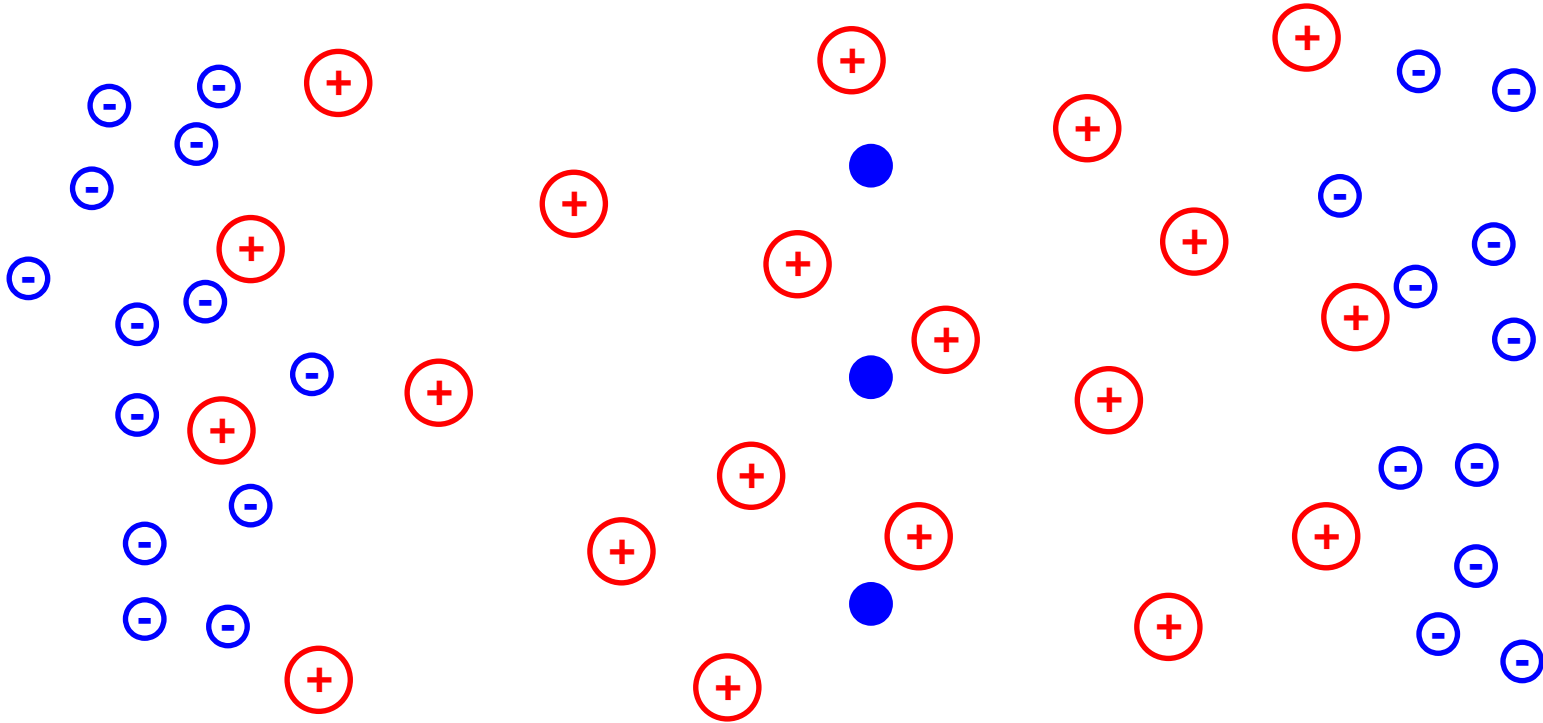
Highly mobile **negative electrons** are quickly repulsed

Heavy **positive ions** remain stationary

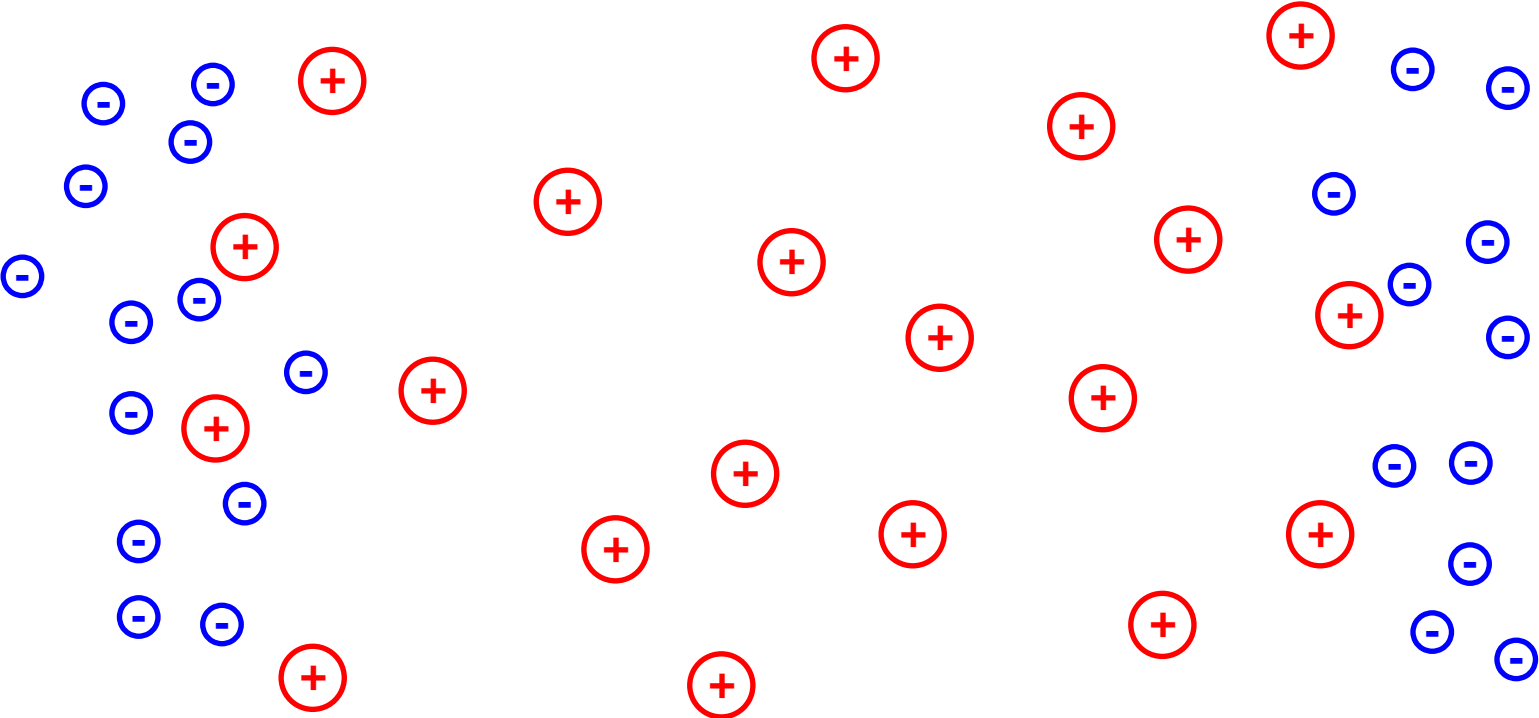




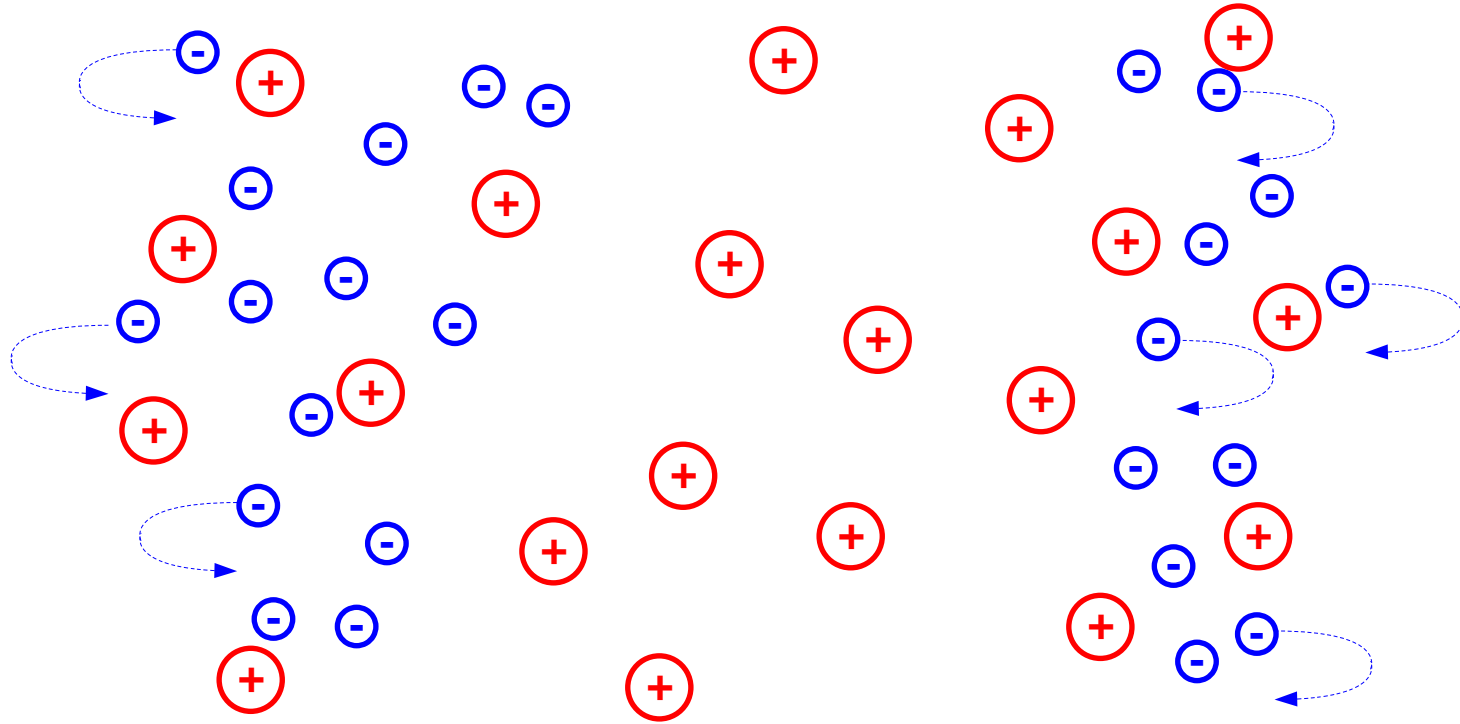
Because **electrons** are so light,  
they *OVERSHOOT* the static screening distance



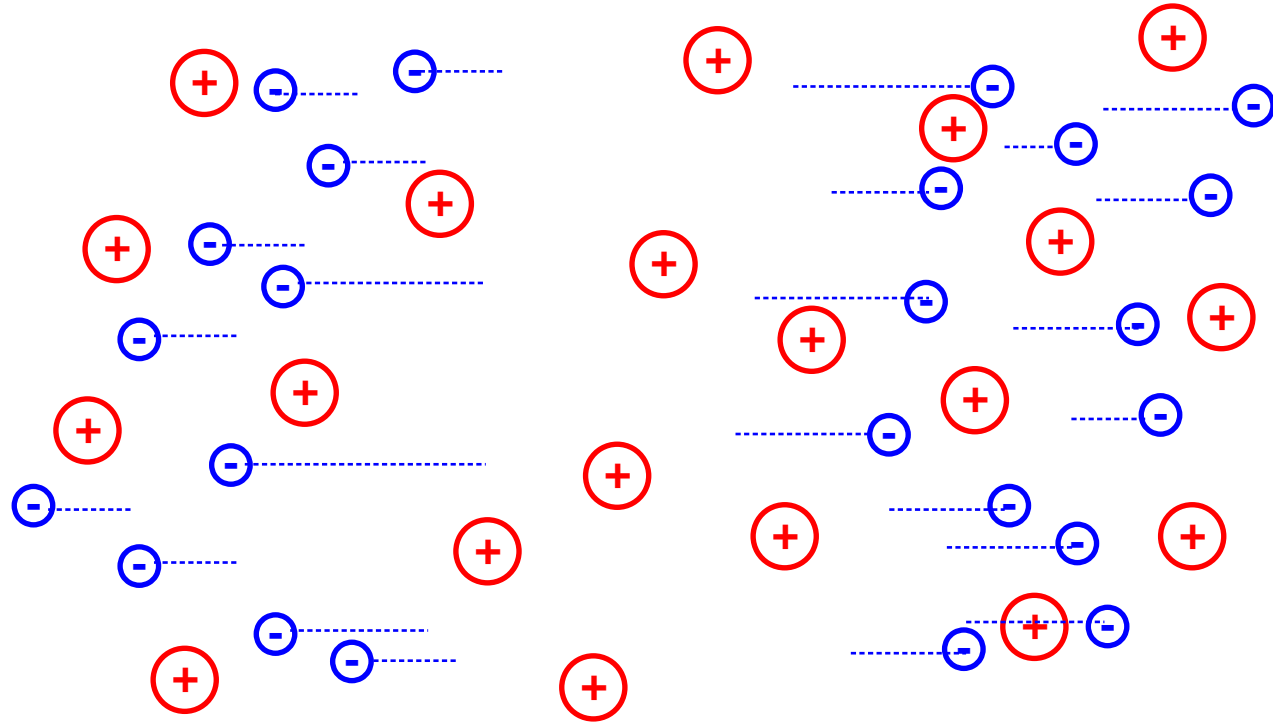
Unscreened **positive ions** exert  
attractive electric force on the **electrons**



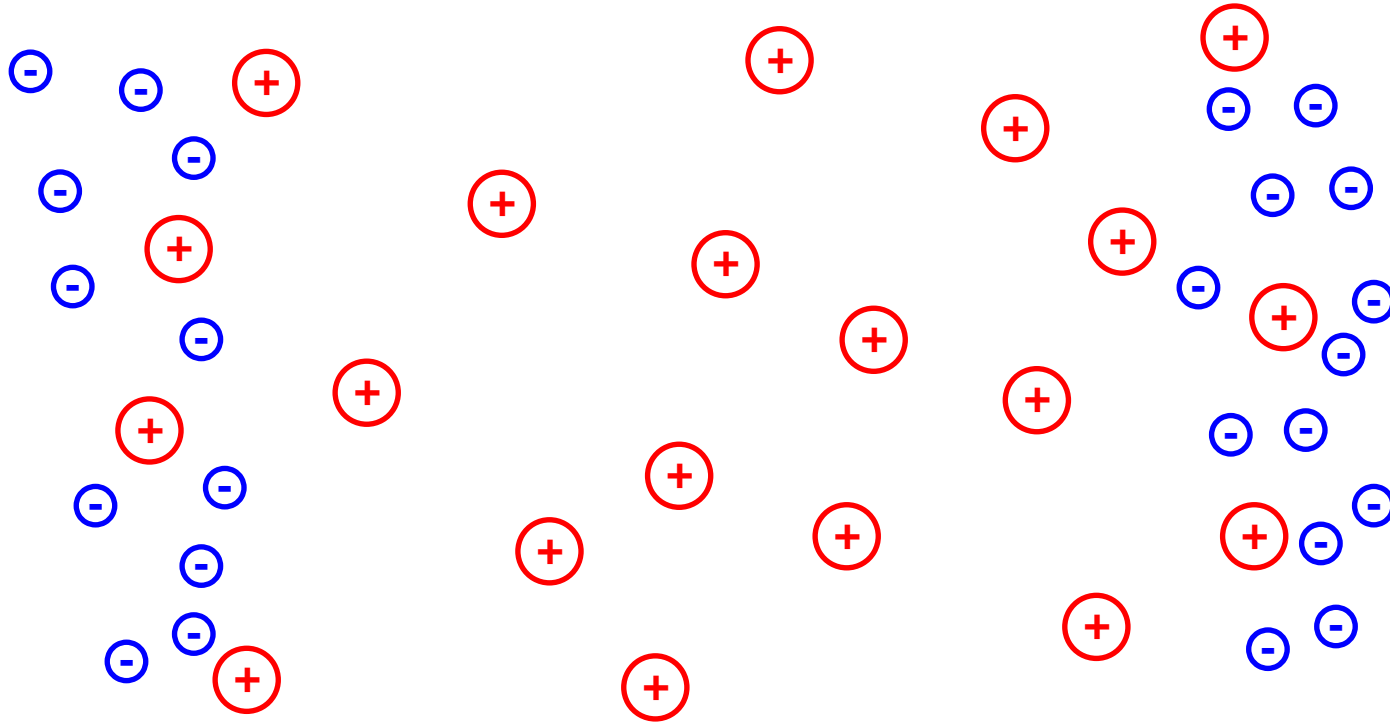
**Electrons stop and get pulled back by the ions**



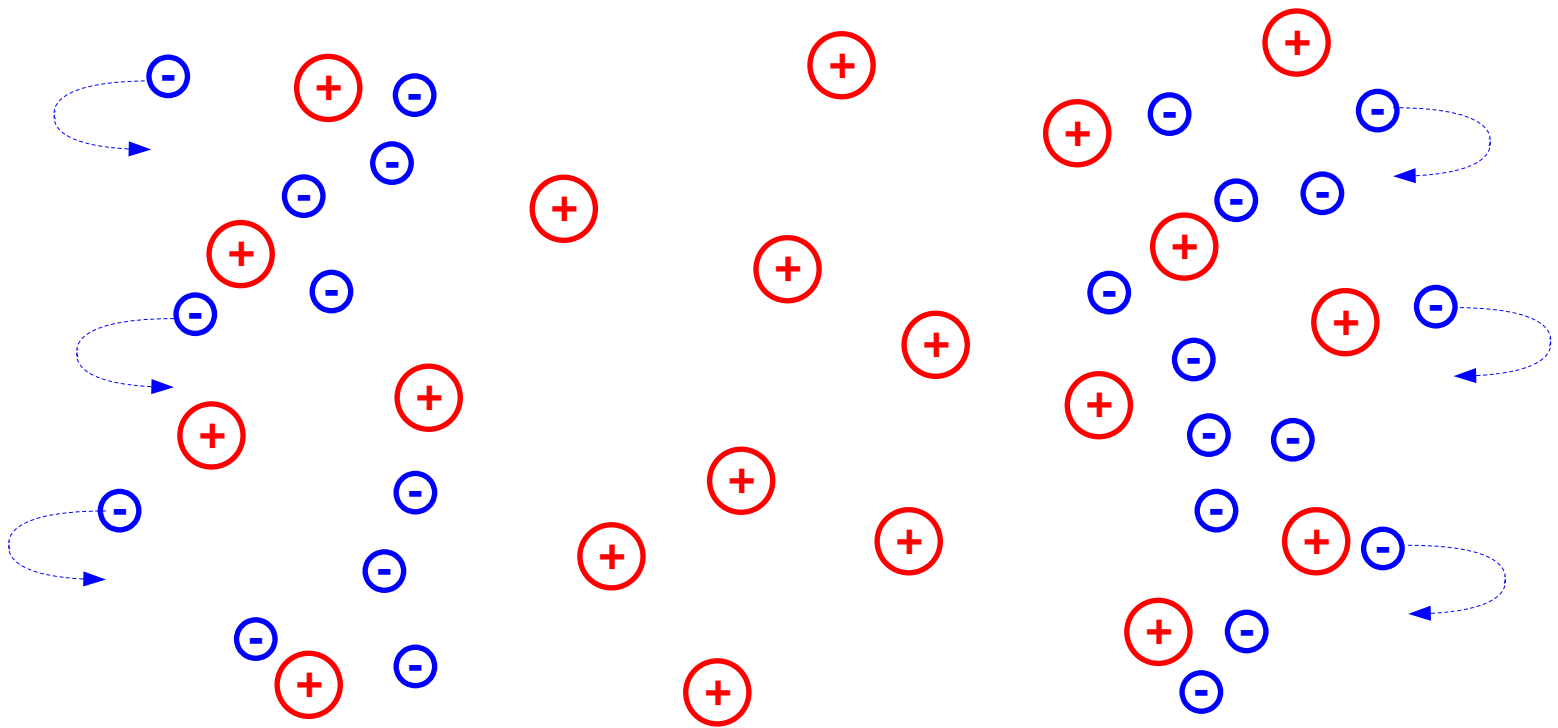
But **electrons** have inertia and overshoot the equilibrium position ...



... until they are stopped again by attractive Coulomb force  
of the **positive ions**

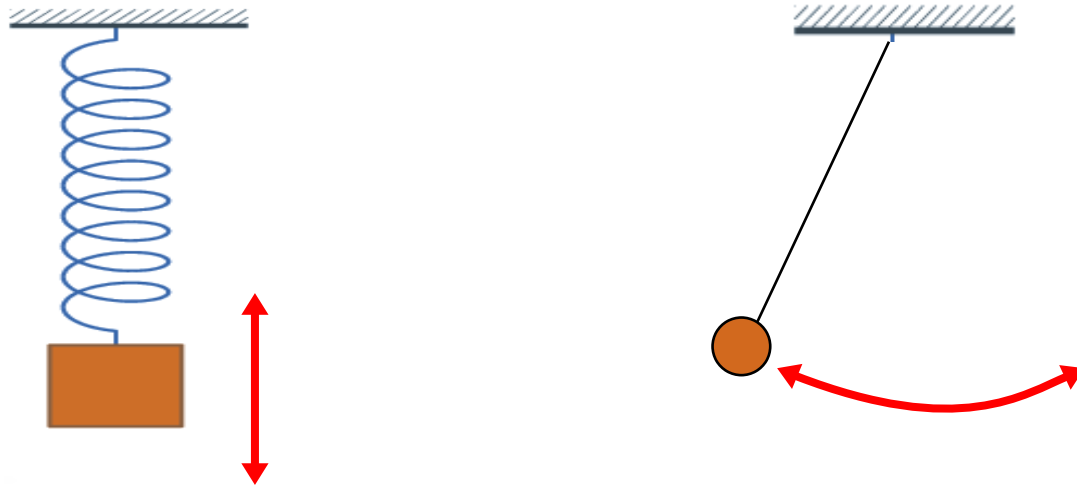


**And the process repeats. This is collective charge oscillation**



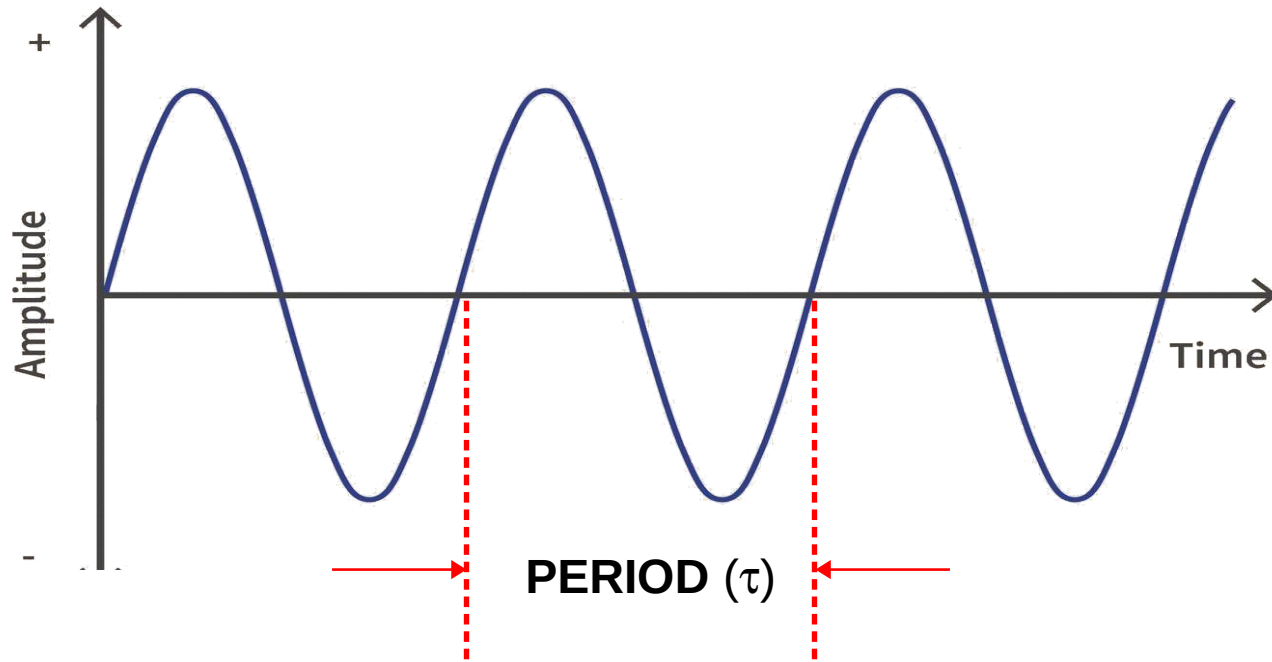
# Classical picture of plasma oscillations

Modeled similar to a vibrating spring or swinging pendulum



**HARMONIC OSCILLATOR**

# HARMONIC OSCILLATOR: Sinusoidal motion with a characteristic frequency



$$\text{FREQUENCY} = \frac{1}{2 \pi \tau}$$



## Natural (resonant) frequency of plasma oscillations ( $f_p$ )\*

$$f_p = \frac{1}{2\pi} \sqrt{\frac{Nq^2}{m\epsilon_0}}$$

$N$ : Density of electrons (or ions)

$q$ : Charge on the electron

$m$ : Mass of the electron

$\epsilon_0$ : Physical constant

\* Also known as the critical frequency

# REFRACTIVE INDEX OF PLASMA (IONOSPHERE)

$$\sqrt{1 - \left(\frac{f_p}{f}\right)^2} = \sqrt{1 - \kappa \frac{N}{f^2}}$$

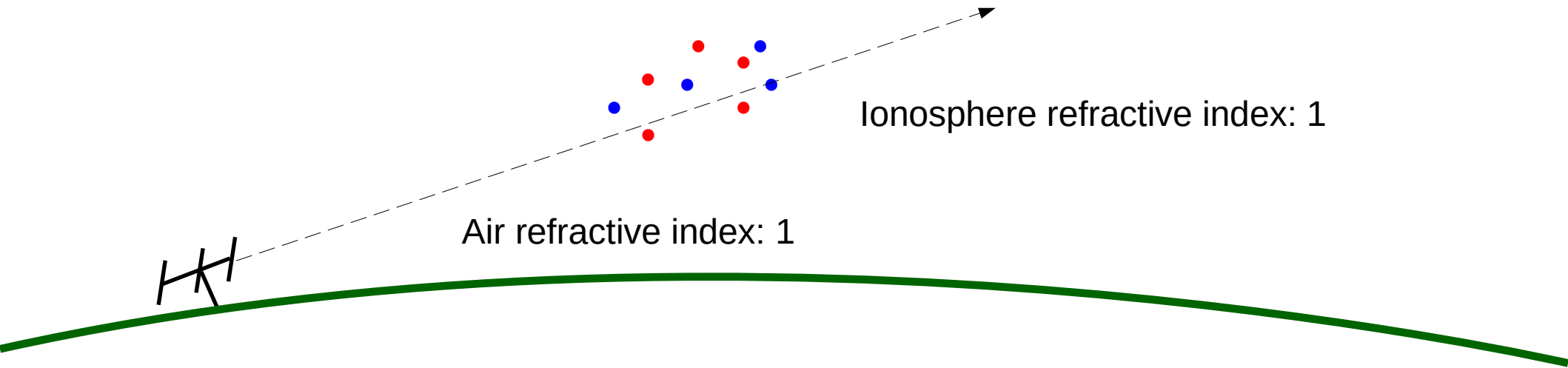
$N$ : Density of electrons (or ions)

$f$ : Frequency of electromagnetic wave

$\kappa$ : Constant

$$\sqrt{1 - \kappa \frac{N}{f^2}}$$

Weak Ionization  $\Rightarrow$   $N$  is small  $\Rightarrow$  Ionosphere Index  $\approx 1$   $\Rightarrow$  Transparent



$$\sqrt{1 - \kappa \frac{N}{f^2}}$$

**Moderate Ionization:** Ionosphere refractive index < 1

Air refractive index: 1



Refraction

Reflection

Depends on plasma density, radio frequency, incidence angle, polarization

$$\sqrt{1 - \kappa \frac{N}{f^2}}$$

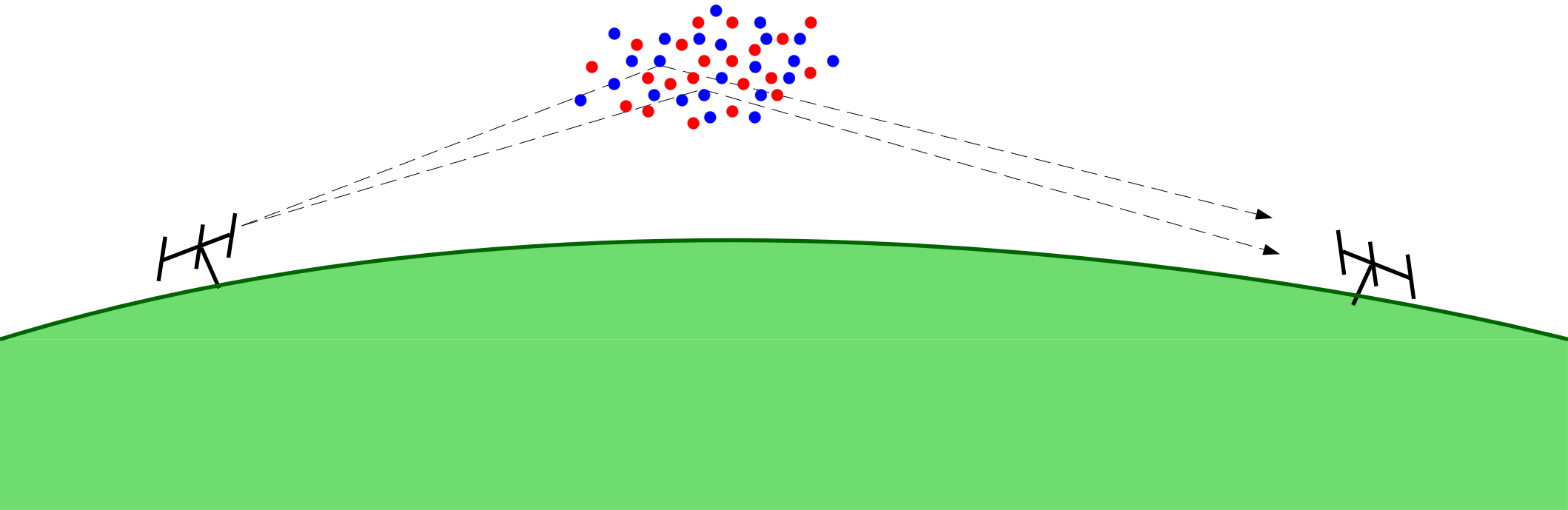
What happens when:  $\kappa \frac{N}{f^2} > 1$  ???

Refractive index of ionosphere becomes imaginary

Ionosphere appears *metallic* to the electromagnetic wave

Metallic ionosphere is opaque

Electromagnetic wave is completely **REFLECTED**

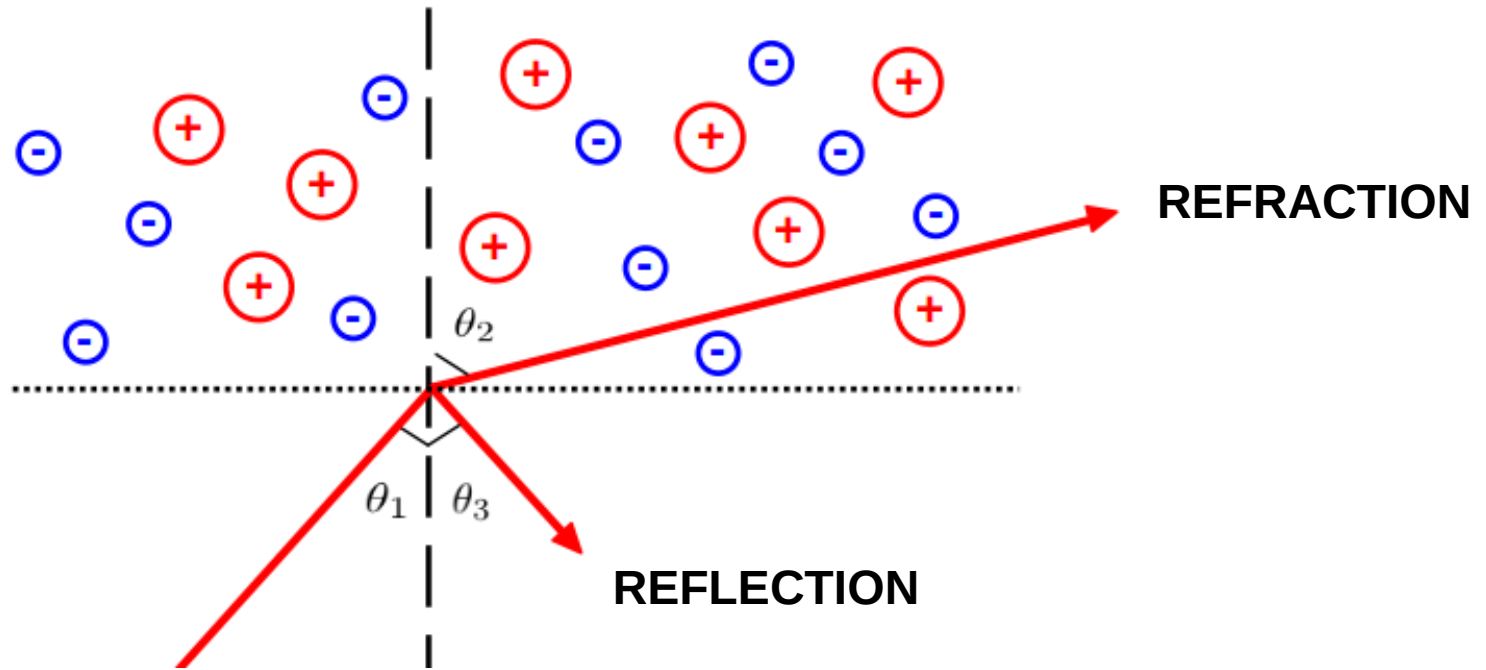


# VHF PROPAGATION

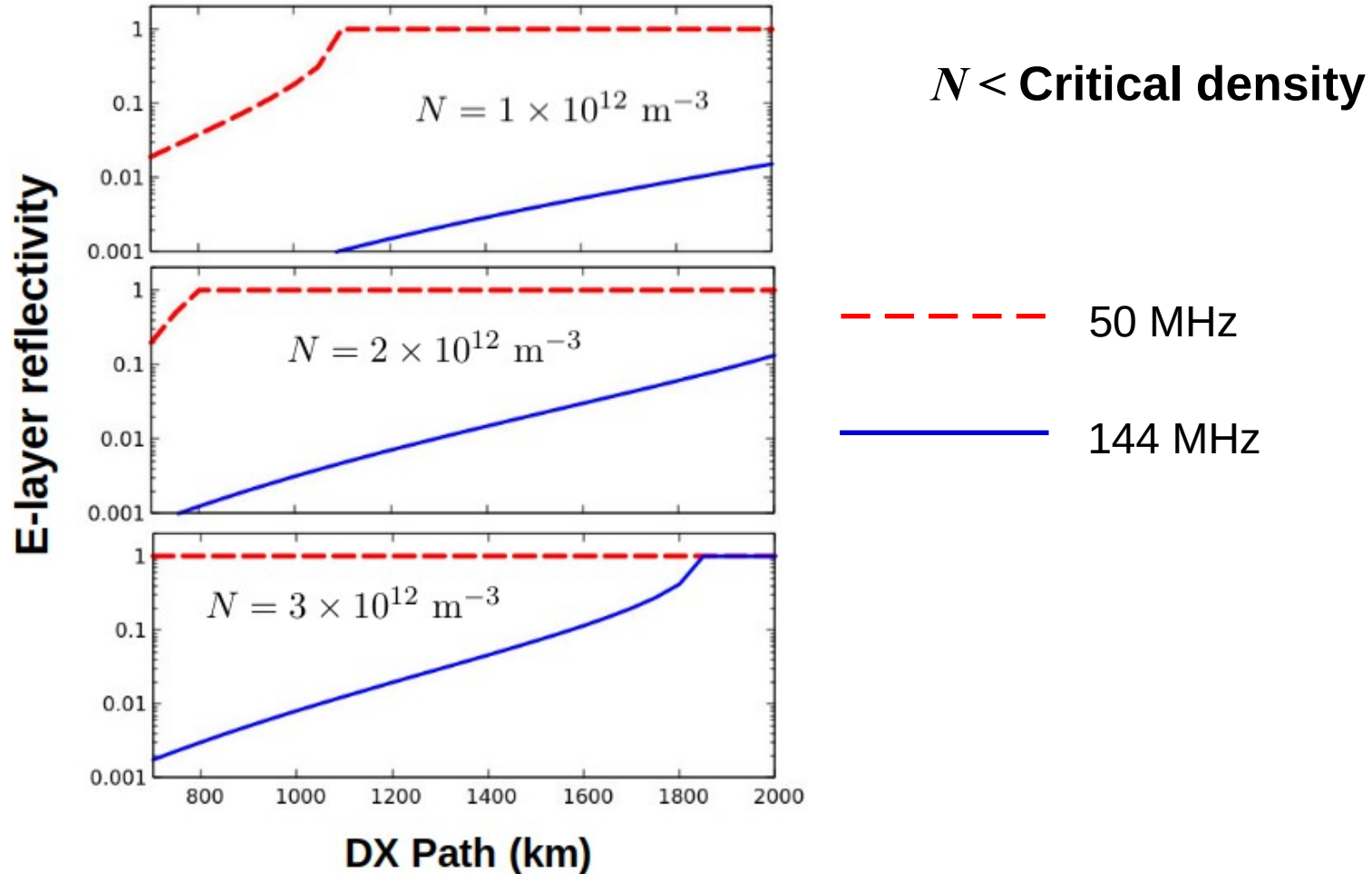
Use classical plasma model to calculate ionosphere reflection at 50 and 144 MHz

$$n_2 = \sqrt{1 - \kappa \frac{N}{f^2}}$$

Air:  $n_1 = 1$



# Calculated Fresnel reflectivity of *E*-layer with increasing ionization





**QUESTION:** When you look in the mirror ...

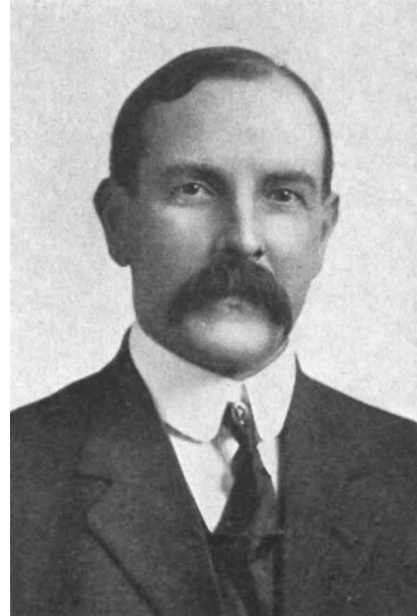
**Are you seeing your reflection or your refraction?**



# ***ACKNOWLEDGEMENTS***



Oliver Heaviside  
1850-1925



Arthur Kennelly  
1861-1939



Edward Appleton  
1892-1965