Pillars of Electrostatics

1. Inverse square law: Force $\propto 1/r^2$

2. Superposition principle

Inverse Square Law

IF we assume that $F_{Coulomb} \propto 1/r^{2+\varepsilon}$

THEN what limit can we place on ε ?

Inverse Square Law

IF we assume that $F_{Coulomb} \propto 1/r^{2+\varepsilon}$

THEN what limit can we place on ε ?

- Cavendish (1772): $|\varepsilon| \leq 0.02$

Inverse Square Law

IF we assume that $F_{Coulomb} \propto 1/r^{2+\varepsilon}$

THEN what limit can we place on ε ?

- Cavendish (1772): $|\varepsilon| \leq 0.02$
- Maxwell (1870s): $|\varepsilon| \leq 5\times10^{-5}$

Inverse Square Law

IF we assume that $F_{Coulomb} \propto 1/r^{2+\varepsilon}$

THEN what limit can we place on ε ?

- Cavendish (1772): $|\varepsilon| \leq 0.02$
- Maxwell (1870s): $|\varepsilon| \leq 5\times10^{-5}$
- Plimpton and Lawson (1936): $|\varepsilon| \leq 2\times10^{-9}$

Inverse Square Law

IF we assume that $F_{Coulomb} \propto 1/r^{2+\varepsilon}$

THEN what limit can we place on ε ?

- Cavendish (1772): $|\varepsilon| \leq 0.02$
- Maxwell (1870s): $|\varepsilon| \leq 5\times10^{-5}$
- Plimpton and Lawson (1936): $|\varepsilon| \leq 2\times10^{-9}$
- Williams, Faller, and Hill (1971): $\varepsilon = (2.7 \pm 3.1) \times 10^{-16}$

Inverse Square Law
vs.
Quantum Electrodynamics

For r << $\lambda_{Compton}$ QED renormalizes the charge of the e^-

$$V(r) = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

$$\lambda_{Compton} = \frac{h}{mc}$$
$$= 2.4 \times 10^{-12} \text{ m for } e^-$$

$$\alpha \simeq \frac{1}{137}$$

Inverse Square Law
vs.
Quantum Electrodynamics

For r << $\lambda_{Compton}$ QED renormalizes the charge of the e^-

$$V(r) = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}\left(1 - \frac{2\alpha}{3\pi}\ln(r/\lambda_{Compton})\right)$$

$$\lambda_{Compton} = \frac{h}{mc}$$
$$= 2.4 \times 10^{-12} \text{ m for } e^-$$

$$\alpha \simeq \frac{1}{137}$$

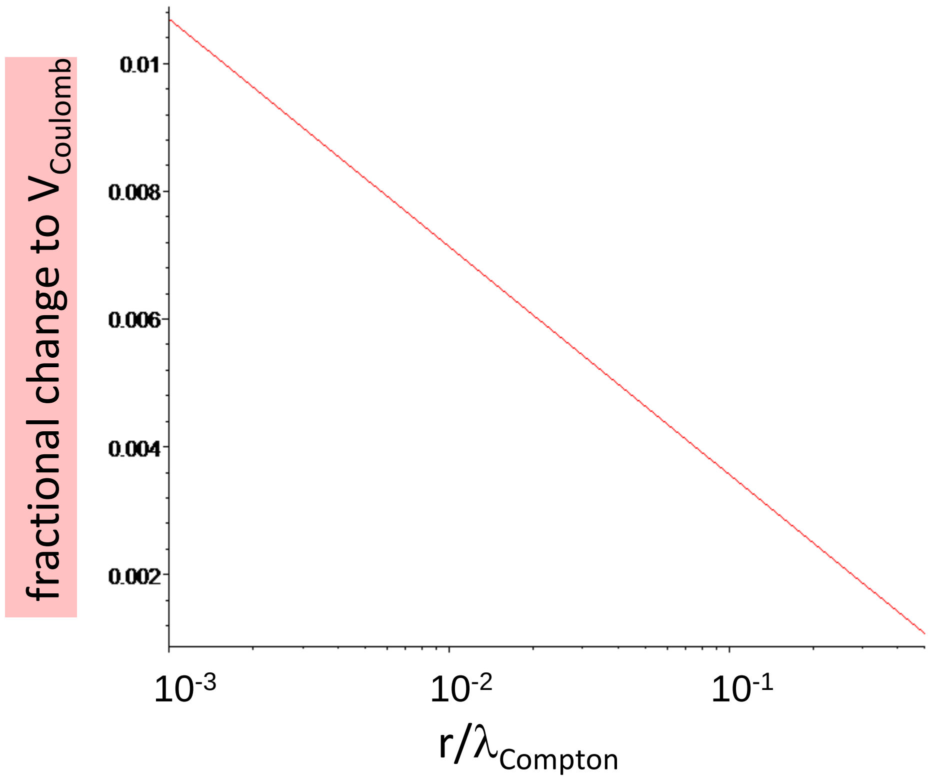
Inverse Square Law
vs.
Quantum Electrodynamics

For r << $\lambda_{Compton}$ QED renormalizes the charge of the e^-

$$V(r) = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}\left(1 - \frac{2\alpha}{3\pi}\ln(r/\lambda_{Compton})\right)$$

$$\lambda_{Compton} = \frac{h}{mc}$$
$$= 2.4 \times 10^{-12} \text{ m for } e^-$$

$$\alpha \simeq \frac{1}{137}$$

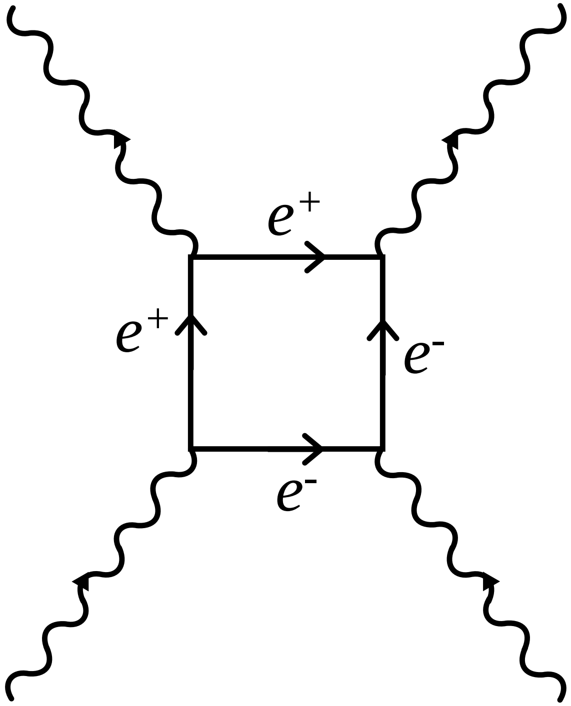


Superposition Principle

In vacuum, the superposition principle ($\vec{E}_{total} = \vec{E}_1 + \vec{E}_2$) is true.

How true?
QED predicts that photons begin to interact with each other (vacuum polarization effect) for

$$E - field \sim 10^{18}\, V/m$$
$$B - field \sim 10^{9}\, T$$



Photon-photon scattering in vacuum has NOT been detected yet.

In non-linear optical media, photon-photon scattering is a common effect.

Note : $E_{max,LAB} \sim 10^{14}\, V/m$ (ultrafast laser pulse)

Conclusion

1. Inverse square law: Force $\propto 1/r^2$

2. Superposition principle

Both of these statements are true over the range of experimental conditions where one would use classical electrodynamics/electrostatics.