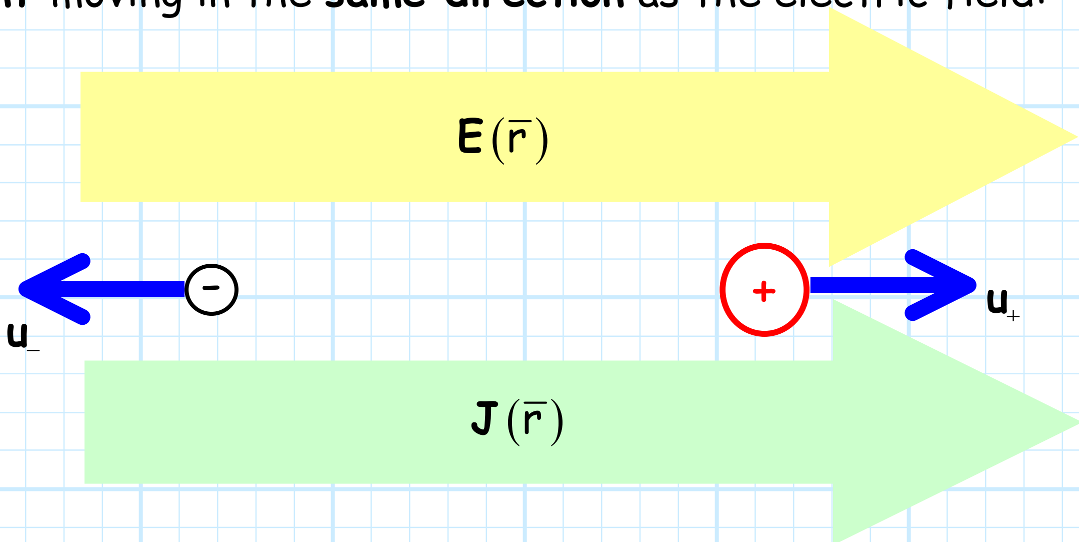
Ohm's Law

Recall that a positively charge particle will move in the direction of an electric field, whereas a negative chare will move in the opposite direction. Both types of charge, however, result in **current** moving in the **same direction** as the electric field:



Q: *So, the direction of current density* $\mathbf{J}(\bar{r})$ *and electric field* $\mathbf{E}(\bar{r})$ *are the same. The question then is, how are their* ***magnitudes*** *related?*

A: They are related by **Ohm's Law**:

$$\mathbf{J}(\bar{r}) = \sigma(\bar{r})\,\mathbf{E}(\bar{r})$$

The scalar value $\sigma(\bar{r})$ is called the material's **conductivity**. Note the units of conductivity are:

$$\sigma(\bar{r}) = \frac{\mathbf{J}(\bar{r})}{\mathbf{E}(\bar{r})} \qquad \left(\frac{\text{Amps}}{\text{m}^2}\right)\left(\frac{\text{Volts}}{\text{m}}\right)^{-1}$$

$$= \frac{\mathbf{J}(\bar{r})}{\mathbf{E}(\bar{r})} \qquad \left(\frac{\text{Amps}}{\text{m}^2}\right)\left(\frac{\text{m}}{\text{Volts}}\right)$$

$$= \frac{\mathbf{J}(\bar{r})}{\mathbf{E}(\bar{r})} \qquad \left(\frac{\text{Amps}}{\text{Volts}\cdot\text{m}}\right)$$

$$= \frac{\mathbf{J}(\bar{r})}{\mathbf{E}(\bar{r})} \qquad \left(\frac{1}{\text{Ohm}\cdot\text{m}}\right)$$

In other words, the unit of conductivity is **conductance/unit length.**

We emphasize that conductivity $\sigma(\bar{r})$ is **a material parameter**. For example, the conductivity of **copper** is:

$$\sigma_{copper} = 5.8 \times 10^{7} \left[\frac{1}{\Omega\,\text{m}}\right]$$

and the conductivity of **polyethylene** (a plastic) is:

$$\sigma_{polyethylene} = 1.5 \times 10^{-12} \left[\frac{1}{\Omega\,\text{m}}\right]$$

Note the **vast** difference in conductivity between these two materials. Copper is a **conductor** and polyethylene is an **insulator**.

Georg Simon Ohm (1789-1854) was the German physicist who in 1827 discovered the law that the current flow through a conductor is proportional to the voltage and inversely proportional to the resistance. Ohm was then a professor of mathematics in Cologne. His work was **coldly** received! The Prussian minister of education announced that "a professor who preached such heresies was unworthy to teach science." Ohm resigned his post, went into academic exile for several years, and then left Prussia and became a professor in Bavaria.

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