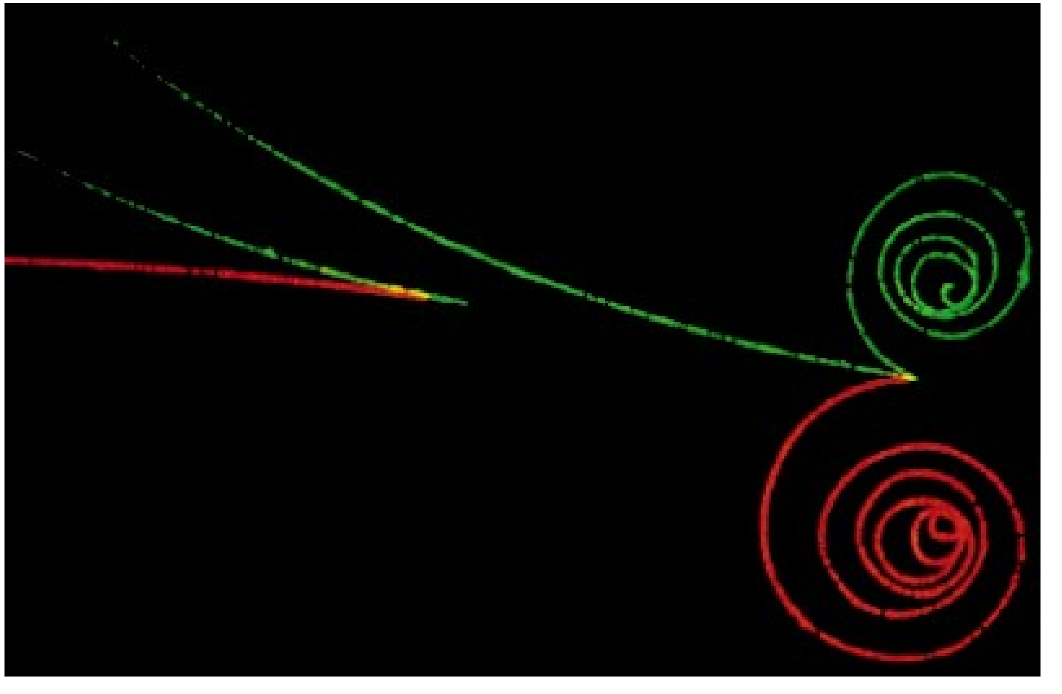
Electricity and Magnetism



Dr Jacob Dunningham, School of Physics and Astronomy, University of Leeds

Overview : The plan for this lecture

- Introduce the module:
  - objectives
  - syllabus
  - forms of teaching and learning
  - resources
- Characteristics of electric charge:
  - quantised
  - conserved
  - unit
- Force from a point charge:
  - Coulomb's law
- Summary

Module Objectives: By the end of the module to be able to ....

- explain the concept of electric and magnetic **fields**;
- find the **electric field** and **potential** around charge distributions through integration;
- find the **magnetic field** generated by current elements through integration;
- calculate the **force on a moving charge** in an electric and magnetic field;
- find the **energy stored** in electric fields using capacitance;
- calculate voltages and currents in DC circuits using **Kirchhoff's rules**.

Relevant textbook chapters

Physics for Scientists and Engineers
Paul A. Tipler & Gene Mosca, 5th edition

Chapter	21	The Electric Field I: Discrete Charge Distributions
	22	The Electric Field II: Continuous Charge Distributions
	23	Electric Potential
	24	Electrostatic Energy and Capacitance
	25	Electric Current and Direct Current Circuits
	26	The Magnetic Field
	27	Sources of the Magnetic Field

I will highlight the relevant sections from each Chapter throughout the course

Teaching and assessment

- **Contact details**
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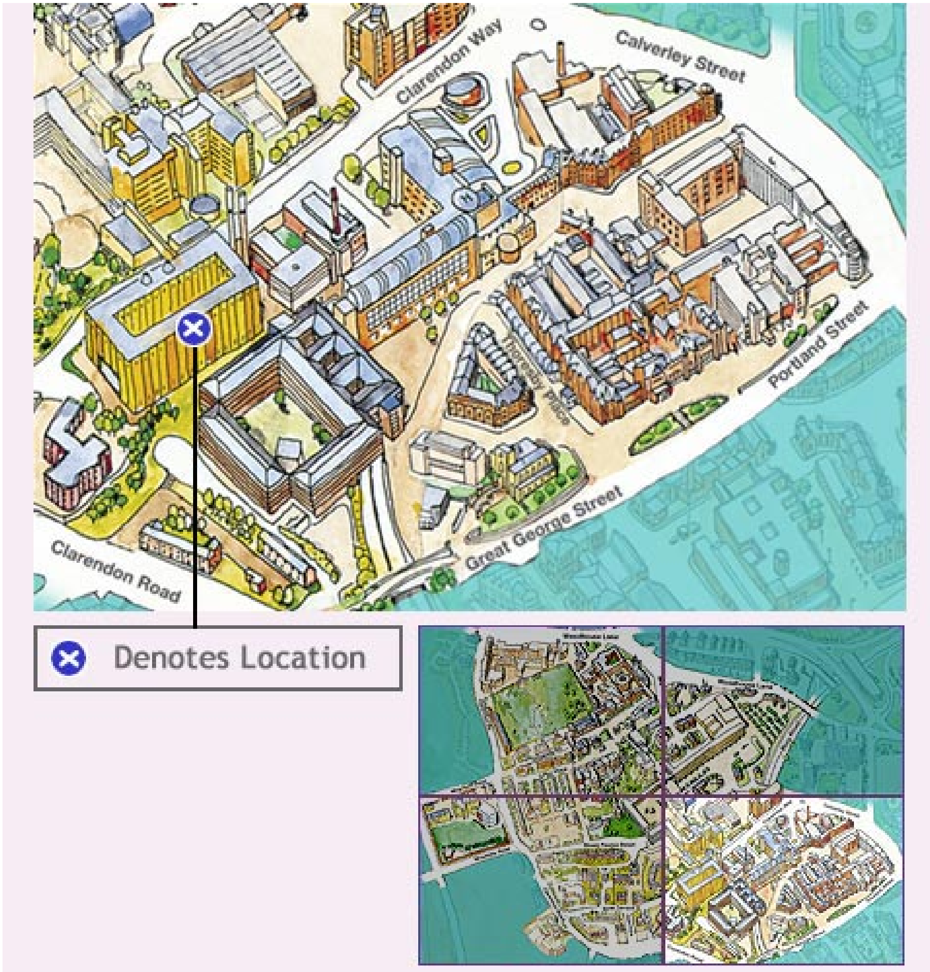
- **Teaching methods**
  Lectures: 12 x 1 hour:
    Mondays 3pm (RSLT20) and Thursdays 4pm (RSLT25)
    The Monday lecture on weeks 7 - 10 will be 'workshop style'
    Rooms: ECS 7.70, SR2, Worsley BS9.57
  Tutorials: Problem solving exercises

- **Methods of assessment (for whole module)**
  1 x 2 hour written examination at the end of the semester: 85%;
  Marked work from weekly problem sheets: 15%.

Worsley Building



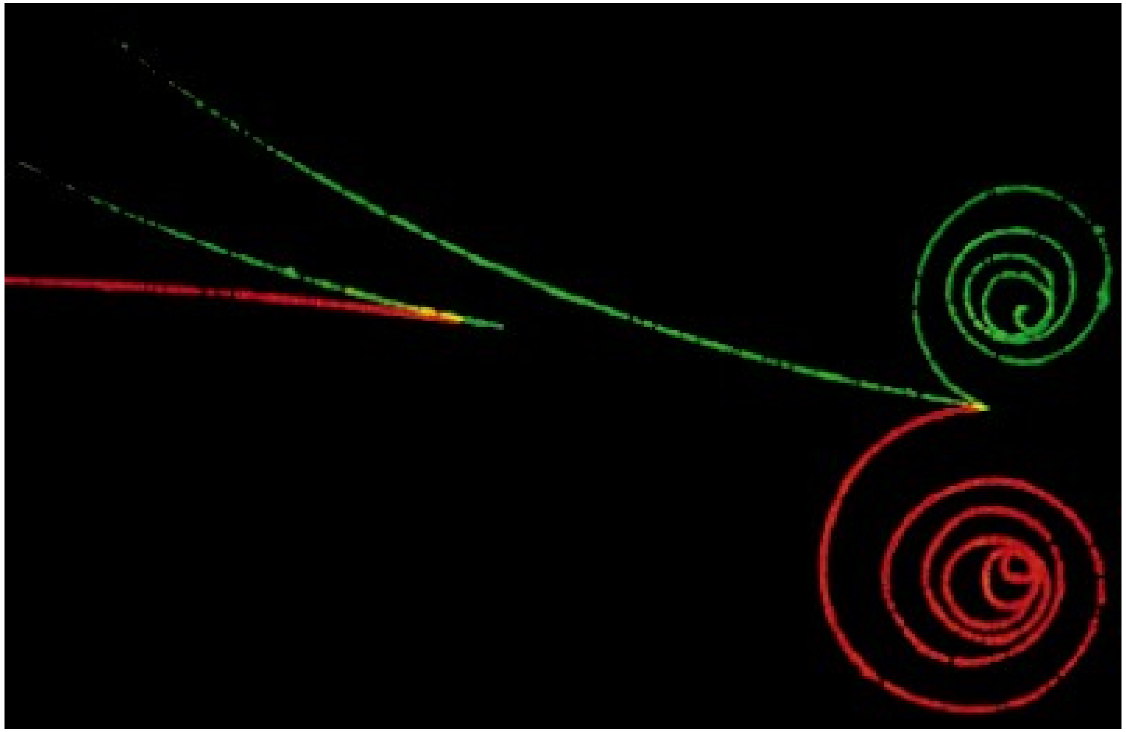
Resources

- Textbook: Tipler & Mosca, *Physics for Scientists and Engineers*
- Other useful textbooks (University Library):
  - M Alonso, E J Finn, *Physics*, £32
  - *Feynman Lectures on Physics*, 3 volumes, £81
  - W Greiner, S Soff, *Classical Electrodynamics*, £36
  - W J Duffin, Electricity and Magnetism, £47
- Module web site at `http://www.dunningham.org/phys1200.html`.

  Lecture slides will be put there a few days after the lecture
  Additional material: e.g handouts and past exam papers*

*N.B. The syllabus was quite different in previous years. I will advise which parts are relevant.

Electric Charge



- The ancient Greeks first discovered electricity, when they noticed that rubbed amber would attract objects

- The Greek word for amber is *elektron*

- A similar principle applies when we get a 'static' shock and also to lightening rods on buildings and cautious eighteenth century women!

`http://phet-web.colorado.edu`

Electric charge is **quantised**

Electron electric charge:	-1 e
Leptons	
Electron, muon, tau:	-1 e
Neutrinos $(\nu_e, \nu_\mu, \nu_\tau)$	0 e
Quarks	
up, charm, top:	$+\frac{2}{3}$ e
down, strange, bottom:	$-\frac{1}{3}$ e
Baryonic matter	
Proton (uud) $= (+\frac{2}{3}, +\frac{2}{3}, -\frac{1}{3})$:	$+1$ e
Neutron (udd) $= (+\frac{2}{3}, -\frac{1}{3}, -\frac{1}{3})$:	0 e

Electric charge is **conserved**

In interactions among elementary particles:

1. equal quantities of positive and negative charge are produced or destroyed

2. the net charge of the Universe is unchanged

Example 1: Neutron decay $(udd) \rightarrow (uud)$

$$d(-\frac{1}{3}) \rightarrow u(+\frac{2}{3})\ e(-1)\ \overline{\nu}_e(0)$$

Example 2: photon-photon collision

$$\gamma(0)\ \gamma(0) \rightarrow e(-)\ e(+)$$

SI unit of electric charge

The SI unit of electric charge is the **Coulomb**.

In units of Coulombs the electron charge is

$$-1\,\mathrm{e} = 1.602176462... \times 10^{-19}\,\mathrm{C}$$

The SI defines charge as a derived unit in terms of the base units current (ampere A) and time (seconds s).

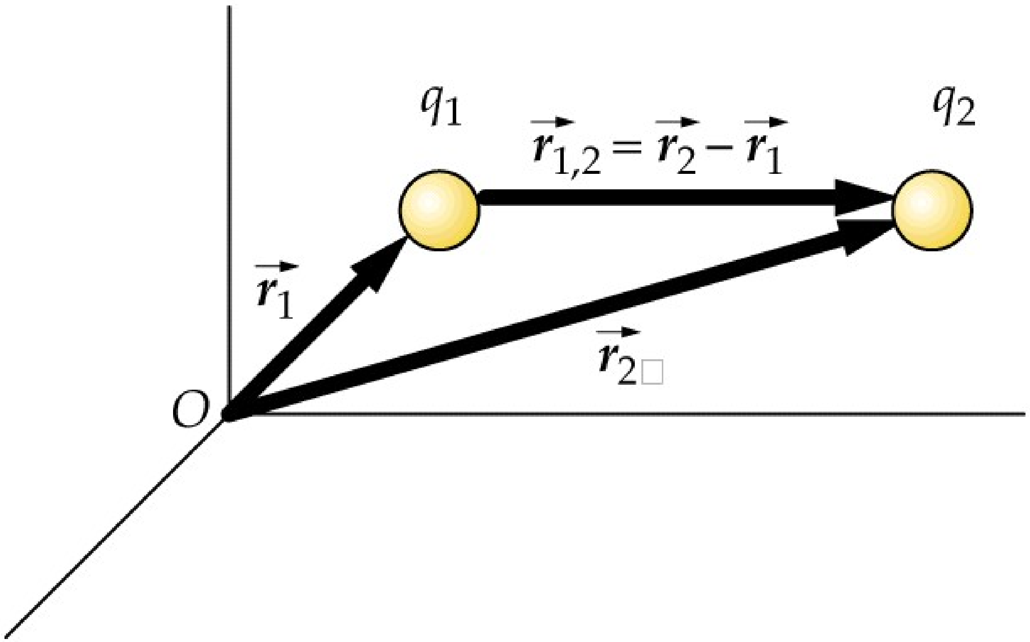
$$1\,\mathrm{C} = 1\,\mathrm{A}\cdot\mathrm{s}$$

There are even moves to define the kilogram electronically.

Exact definitions of units by the *Bureau International des Poids et Mesures* at `http://www.bipm.fr`

For the latest *Adjustment of the Fundamental Physical Constants* from the *Committee on Data for Science and Technology (CODATA)* visit `http://www.codata.org`.

Force between point charges



The **magnitude** of the electric force F by charge q_1 on another charge q_2 at distance r is

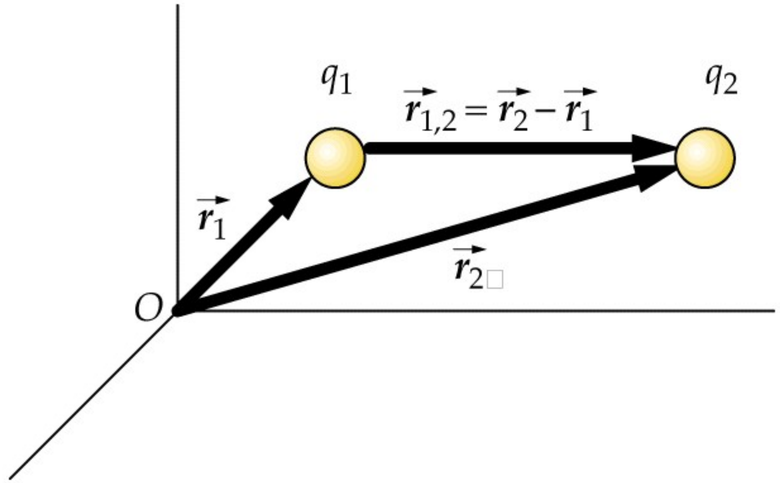
$$F = k \cdot \frac{q_1 \cdot q_2}{r^2}$$

- Coulomb's constant k is experimentally determined:

$$k = 8.99 \cdot 10^9 \, \frac{Nm^2}{C^2}$$

- Force is either repulsive or attractive. Depends on the relative sign of charges.
- Force depends on distance between charges. Inverse square law similar to Newtons law.

Coulomb's law in vector form



Force $\vec{\mathbf{F}}_{1,2}$ exerted by a charge q_1 on another charge q_2 at distance r:

$$\vec{\mathbf{F}}_{1,2} = k \cdot \frac{q_1 \cdot q_2}{r_{1,2}^2} \cdot \hat{\mathbf{r}}_{1,2}$$

where the unit vector $\hat{\mathbf{r}}_{1,2}$ is defined as

$$\hat{\mathbf{r}}_{1,2} \;=\; \frac{\vec{\mathbf{r}}_2 - \vec{\mathbf{r}}_1}{|\vec{\mathbf{r}}_2 - \vec{\mathbf{r}}_1|}$$

Numerical example: comparison with gravitational force

Compute the ratio of the electric force to the gravitational force exerted by a proton on the electron in Hydrogen.

Numerical example: comparison with gravitational force

Ratio of forces:

$$F_e = k\,\frac{e^2}{r^2}$$
$$F_g = G\,\frac{m_p \cdot m_e}{r^2}$$
$$\frac{F_e}{F_g} = \frac{k}{G}\,\frac{e^2}{m_p \cdot m_e}$$

(N.B. Don't need to know the separation)

With the constants

$$\begin{aligned} G &= 6.67 \cdot 10^{-11}\text{Nm}^2/\text{kg}^2 \\ k &= 8.99 \cdot 10^{9}\text{Nm}^2/\text{C}^2 \\ e &= 1.6 \cdot 10^{-19}\text{C} \\ m_p &= 1.67 \cdot 10^{-27}\text{kg} \\ m_e &= 9.11 \cdot 10^{-31}\text{kg} \end{aligned}$$

this gives a ratio of

$$\frac{F_e}{F_g} = 2.27 \cdot 10^{39} \quad \text{(2270 trillion trillion trillion)}$$

Side remark: other forces

- Electromagnetism dominates at the subatomic and atomic level.
- For large and electrical neutral objects, for example stars and planets, the net force is essentially only the gravitational force.
- At nuclear or sub-nuclear distances the weak interaction and/or the strong interaction often dominate.
- The Minimal Standard Model (MSM) of particle physics combines three forces (electromagnetic, weak, strong) into one model.

Summary

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- Electric charge is quantised and conserved.

- Coulomb's law

$$\vec{\mathbf{F}}_{1,2} = k \cdot \frac{q_1 \cdot q_2}{r_{1,2}^2} \cdot \hat{\mathbf{r}}_{1,2}$$

Recommended reading in Tipler

Sections 21-1 to 21-3

Preparation for next lecture

Electric Field (21-4),

Electric Field Lines (21-5).