

# Introduction to Electromagnetism

UNIVERSITY OF  
Southampton

## Physics and Astronomy

### PHYS1022 - Electricity and Magnetism



This course is a first introduction to classical electromagnetism taking you through to Maxwell's equations in integral form. The syllabus is [here](#).

#### Important Dates and Times for Semester 1, 2019:

- Lecture 1 & 2: 11am-1pm monday, Building 7 Room 3009 (LT A)
- Lecture 3: 11am-noon tuesday, Building 7 Room 3009 (LT A)
- Problem workshops: 3-4pm thursday, Building 46 Room 2003 (LT B)  
& 9-10am friday, Building 46 Room 2003 (LT B)
- Geophysics tutorial: tbc

Course work - there is a weekly on-line problem sheet which counts towards your course mark. You may access this from the Mastering Physics link on the [blackboard page](#) for this course.

[www.soton.ac.uk/~evans/PHYS1022...](http://www.soton.ac.uk/~evans/PHYS1022...) or google... or blackboard...  
or off “current students” on school web site

## Resources:

- Lecture notes: [Charge](#), [Electric Force/Field](#), [Gauss' Law](#), [Potential](#), [Circuits](#), [Magnetic Force/Field](#), [Ampere & Faraday's Laws](#), [Maxwell Equations & AC circuits](#)
- Videos of the lectures from a couple of years ago are available (this years can be accessed from blackboard) [here](#)
- The powerpoint slides from lectures: [week 1](#) ;
- Weekly non-assessed tutorial and workshop problem: [week1](#) ;
- Last year's mid-semester [test](#) and [solutions](#) ; 2017's mid-semester [test](#) and [solutions](#)
- A series of powerpoint shows covering the course material are available [here](#)
- A resource teaching PHYSICS KEY SKILLS [here](#)
- A page of videos and notes on the integration used in the course [here](#)
- [Here](#) is a pdf doing that tricky differentiation in gory detail...
- Video tutorials on some "electric" problems [here](#) .
- Video tutorials on some "magnetic" problems [here](#) .
- There are some brief external on-line demos about EM [here](#) and [here](#) .
- Jim Al-Khalili made some super TV programs about the history of E&M called "Shock and Awe" - you can view them for free at [BoB](#) - you can log in with your University login.
- Final example revision sheet for the course [here](#) ; the examination Physical Constant sheet is [here](#)
- Past exam papers are available from the [library](#) . Exam report for 18/19 is [here](#)

## Course Book

You have been given electronic access to “Pearson” – we will use Chps 21-31 (pages 763 – 1161) – access from:

blackboard → Mastering Physics → University Physics with Modern  
Physics, 14e, Young & Freedman (eText)

(There are some hard copies in the Physics labs (level 3 of Bldg 46)  
you can use also)

There are a vast number of other books in the library covering the  
same material – see what you get on with!!

# Hints on Lectures and note-taking

Taking notes is an important skill. The **act of writing** in a lecture should help fix the material in your memory so that it is easier to recall later. What you record in a lecture gives you a reminder of what to go over later, and understand better. **Copies of my hand written notes are on the website.**

In lecture:

- **Copy the board with annotations from what I say!**
- **My powerpoint slides are “background”**
- Listen to what is said. It is difficult to write and listen.
- **Shout at me if I go too fast!**
- Underline or highlight important points.
- Use simple diagrams.
- **If you don't understand something, make a note of it.**

After lecture:

- Read through notes as soon as possible.
- Copy them out again, especially if messy, **adding to them from textbook.**
- Sort out the points you don't understand, read up, ask me, or tutor.
- **Discuss** with friends, as this really helps understanding.

**Assessed Problem sets** will be available online each week –

Blackboard → Mastering Physics → Assignments

These problems must be completed by the set deadline, which will be clearly stated (usually Sunday at 12, midnight).

The unmarked but important introductory exercise is available now and you should do it this week!

They are worth 20% of your course mark. (nerdish analysis shows that students who don't bother fail... no exceptions...)

**Tutorial problems sheets** will also be distributed on Monday for Tutorials and Workshop. They will be available online as well.

They contain conceptual/simple problems to be worked on and discussed in your tutorials.

The problems will be done in your workshops, where help will be available – look at them before workshops but plan to write out the solutions there...

**Workshops for this course start this week... you must attend!**

Answers to these problems will be posted on the course web page after a suitable interval.

**Workshop problems are similar to examination problems.**

I want more questions....

There are a vast number of questions in the e-text we have provided you – at the end of each chapter

Many other books in the library (eg Wolfson) have as many again...

## How do I get feedback on progress?

- Mastering Physics gives you real time hints and solutions when you're done.
- Problem sheet solutions will be on the web site the week after you do them.
- I am available after lectures (particularly in the double slot) to answer questions – use me!
- Demonstrators are available to help you in the problem classes – use them!
- Your tutorial sessions are periods where you can ask anything – go to your tutorials with questions about what you don't understand!
- There will be revision lectures at the end of the semester with free discussion periods too.





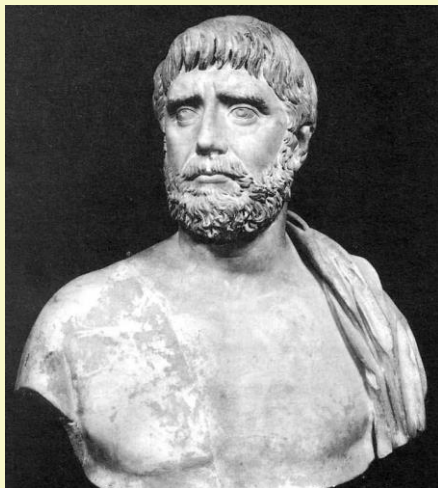
History of E&M... according to Wikipedia(!)

# Triboelectric effect

When touching, some materials claim electrons from the other leaving each with a net charge... it works better if you rub materials together... This property suggested the word "[electricity](#)" (from William Gilbert's initial coinage, "electra"), from the Greek word for amber, *ēlektron*.

**William Gilbert**, also known as **Gilberd**, (1544 – 1603) was an English (Colchester) physician, physicist and natural philosopher. He was an early Copernican, and passionately rejected both the prevailing Aristotelian philosophy and the Scholastic method of university teaching. He is remembered today largely for his book *De Magnete* (1600), and is credited as one of the originators of the term *electricity*. He is regarded by some as the father of electrical engineering or electricity and magnetism.

He worked out the Earth was a magnet and thought quartz was a very hard form of ice... he died of plague..



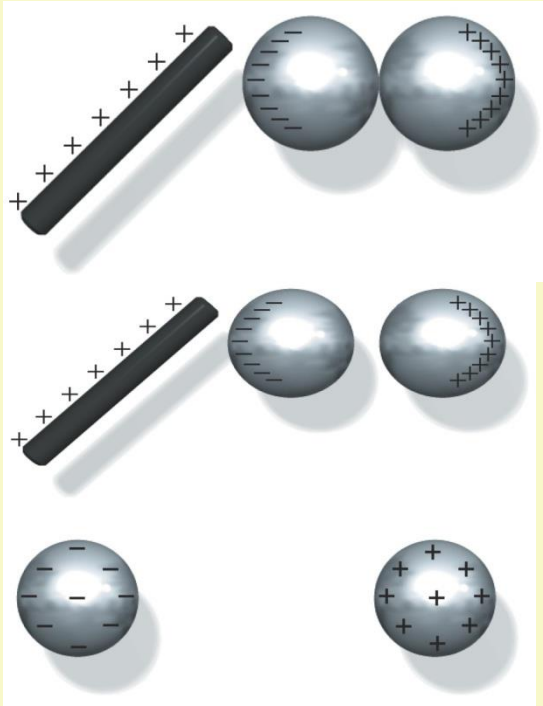
**Thales of Miletus** (624 BC – c. 546 BC, Miles, Turkey – he died of heat stroke watching the Olympics)

one of the Seven Sages of Greece. Many regard him as the first philosopher in the Greek tradition. Thales attempted to explain natural phenomena without reference to mythology. He predicted a solar eclipse and thought all matter has a soul because magnets move.

He rubbed amber on fur and saw it then attracted straw and feathers.

Triboelectric series:
<i>Most positively charged</i>
+
Air
Human skin
Leather
Rabbit's fur
Glass
Quartz
Mica
Human hair
Nylon
Wool
Lead
Cat's fur
Silk
Aluminium
Paper ( <i>Small positive charge</i> )
Cotton ( <i>No charge</i> )
0
Steel ( <i>No charge</i> )
Wood ( <i>Small negative charge</i> )
Lucite
Amber
Sealing wax
Acrylic
Polystyrene
Rubber balloon
Resins
Hard rubber
Nickel, Copper
Sulfur
Brass, Silver
Gold, Platinum
Acetate, Rayon
Synthetic rubber
Polyester

# Charging by induction



(a) Conductors in contact become oppositely charged when a charged rod attracts electrons to the left sphere

(b) if the spheres are separated before the rod is removed, they will retain their equal and opposite charges

(c) When the rod is removed and the spheres are far apart, the distribution of the charge on each sphere approaches uniformity

**John Canton** FRS (1718 –1772, Stroud)

the clerk to the master of a school in Spital Square, London

1745 he made some improvements in electricity.

He also showed water could be compressed and made phosphorus from oyster shells.





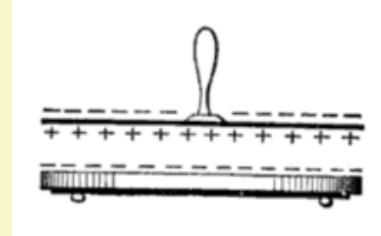
balloonstick.m2ts

# Electrophorous

**Johan Carl Wilcke** (6 September 1732 – 18 April 1796) was a [Swedish physicist](#).

In 1762 he invented an electrostatic generator that was a first version of the electrophorus.

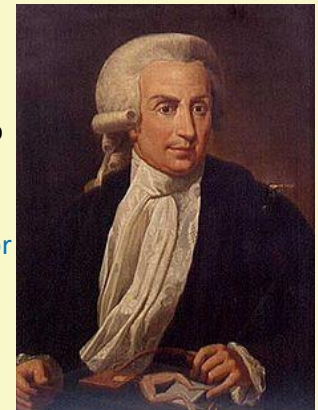
In 1772 he calculated the latent heat of ice. In 1781, he coined the concept and term of "specific heat



# Count Alessandro Volta 1745 –1827

The battery made by Volta is credited as the first electrochemical cell. It consists of two electrodes: one made of [zinc](#), the other of [copper](#). The [electrolyte](#) is [sulfuric acid](#) or a brine mixture of salt and water. The electrolyte exists in the form  $2\text{H}^+$  and  $\text{SO}_4^{2-}$ . The zinc, which is higher than both copper and hydrogen in the electrochemical series, reacts with the negatively charged sulfate ( $\text{SO}_4^{2-}$ ). The positively charged hydrogen ions ([protons](#)) capture [electrons](#) from the copper, forming bubbles of hydrogen gas,  $\text{H}_2$ . This makes the zinc rod the negative electrode and the copper rod the positive electrode.

We now have two terminals, and the current will flow if we connect them



**Luigi Alyisio Galvani** (September 9, 1737 – December 4, 1798) was an Italian physician and physicist who lived and died in [Bologna](#). In 1791, he discovered that the muscles of dead frogs legs twitched when struck by a spark. This was one of the first forays into the study of [bioelectricity](#), a field that still today studies the electrical patterns and signals of the [nervous system](#). He was cutting the frogs' legs [as an experiment trying to prove that a frog's testicles were actually in their legs \(or not\)](#). He was quickly proved wrong by other biologists at the University of Pavia.



We can differentiate...

$$\frac{d}{dx} \text{constant} = 0$$

$$\frac{d}{dx} x^n = nx^{n-1}$$

$$\frac{d}{dx} \sin x = \cos x$$

$$\frac{d}{dx} \cos x = -\sin x$$

$$\frac{d}{dx} \ln x = \frac{1}{x}$$



We can differentiate and integrate...

$$\int (0) dx = \text{constant}$$

$$\int x^n dx = \frac{1}{n+1} x^{n+1} + \text{constant}$$

$$\int \sin x dx = -\cos x + \text{constant}$$

$$\int \cos x dx = \sin x + \text{constant}$$

$$\int \frac{1}{x} dx = \ln x + \text{constant}$$

We can differentiate and integrate...

$$\int_a^b (0)dx = 0$$

$$\int_a^b x^n dx = \frac{1}{n+1}(b^{n+1} - a^{n+1})$$

$$\int_a^b \sin x dx = \cos a - \cos b$$

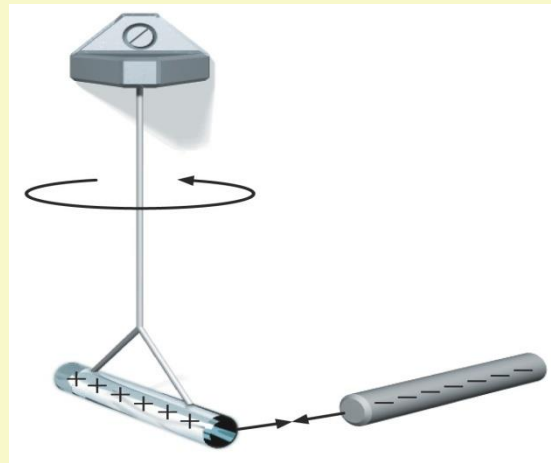
$$\int_a^b \cos x dx = \sin b - \sin a$$

$$\int_a^b \frac{1}{x} dx = \ln b/a$$

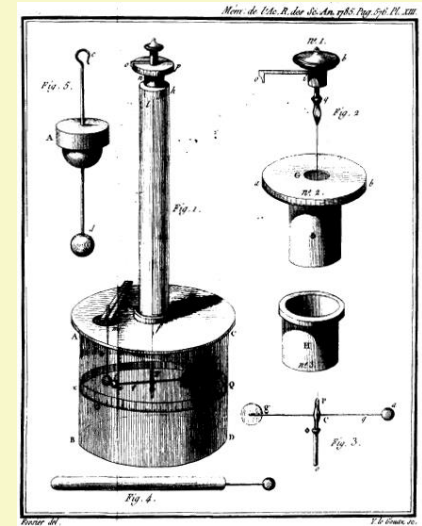




Same signs repel



Opposite signs attract



## Coulomb's Law quantifies the forces drawn



### Charles-Augustin de Coulomb 1736 –1806

Coulomb spent eight years constructing Fort Bourbon, Martinique, contracting tropical fever.

In 1785, Coulomb presented his three reports on Electricity and Magnetism:

- *Premier Mémoire sur l'Electricité et le Magnétisme*.<sup>[2]</sup> In this publication, Coulomb describes "How to construct and use an electric balance (torsion balance) based on the property of the metal wires of having a reaction torsion force proportional to the torsion angle." Coulomb also experimentally determined the law that explains how "two bodies electrified of the same kind of Electricity exert on each other."

- *Deuxieme Mémoire sur l'Electricité et le Magnétisme*.<sup>[3]</sup> In this publication, Coulomb carries out the "determination according to which laws both the Magnetic and the Electric fluids act, either by repulsion or by attraction."

- *Troisième Mémoire sur l'Electricité et le Magnétisme*.<sup>[4]</sup> "On the quantity of Electricity that an isolated body loses in a certain time period, either by contact with less humid air or in the supports more or less idio-electric."

# Joseph Priestley (1733 -1804)

He is usually credited with the discovery of oxygen (dephlogisticated air)

His considerable scientific reputation rested on his invention of soda water

The intellectually stimulating atmosphere of Warrington, often called the "Athens of the North" during the 18th century, encouraged Priestley's growing interest in natural philosophy

Priestley was also the first to propose that electrical force followed an inverse-square law



# Henry Cavendish FRS (1731–1810)

Cavendish was silent and solitary, and was viewed as somewhat eccentric by many. He only spoke to his female servants by notes

His only social outlet was the Royal Society Club

those who "sought his views... speak as if into vacancy. If their remarks were...worthy, they might receive a mumbled reply, but more often than not they would hear a peeved squeak (his voice appears to have been high-pitched) and turn to find an actual vacancy and the sight of Cavendish fleeing to find a more peaceful corner"

Maxwell discovered Cavendish had discovered Coulomb's law but not published it



# Institute of Physics EM Test

On Friday 05 October there will be a multiple choice test on the conceptual understanding of electricity and magnetism. Participation is entirely voluntary and the test does NOT form part of the assessment of the course PHYS1022 (Electricity & Magnetism). This test is designed to assess the conceptual understanding of students before and after the teaching of a course on electricity & magnetism. There will be another sitting of the test at the start of the second semester (end of January 2019). The scores from the tests are used to assess the teaching.

It is your decision whether you attend, but your participation would be appreciated. It is not necessary to let me know whether or not you will sit the test. The date, time and room of the test are:

Friday 04 October

1400-1445

Room 1001 in Building 35

Please note that this time and place is a problem class slot of the course PHYS1015 (Motion & Relativity), but there will be no problem class on that day - this test replaces the problem class.

A personal identification number will be given to you as you hand in your answer sheet. This number is to be written on the answer sheet instead of your name. Your consent is obtained by you filling in a circle on the answer sheet (your signature is not used).

On the answer sheet you are also asked to provide information on your entry qualifications, highest grade obtained in Maths and Physics, first language, gender, and degree course. This extra information is entirely voluntary, and you can sit the test without providing this information. More details will be given in the test room.

If you have any questions please feel free to contact me at "a.g.akeroyd@soton.ac.uk", and not to Nick Evans (lecturer of PHYS1022). As stated above, participation in these tests is entirely voluntary and the tests do NOT form part of the assessment of the course PHYS1022. It is your decision whether you attend, but your participation would be appreciated.





# Coulomb's Law

The **magnitude and direction** of the electric force exerted by a charge  $q_1$  on another charge  $q_2$  a distance  $r$  away is given by

$$\vec{F}_{12} = \frac{kq_1q_2}{r^2} \hat{r} \quad (\text{Coulomb's law}) \quad (20.1)$$

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where  $k$  is an experimentally determined constant

$$k = 9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2 \quad (= 1/4\pi\epsilon_0)$$

notation

unit vector



### Some Electric Fields in Nature

	$E, \text{N/C}$
In household wires	$10^{-2}$
In radio waves	$10^{-1}$
In the atmosphere	$10^2$
In sunlight	$10^3$
Under a thundercloud	$10^4$
In a lightning bolt	$10^4$
In an X-ray tube	$10^6$
At the electron in a hydrogen atom	$6 \times 10^{11}$
At the surface of a uranium nucleus	$2 \times 10^{21}$

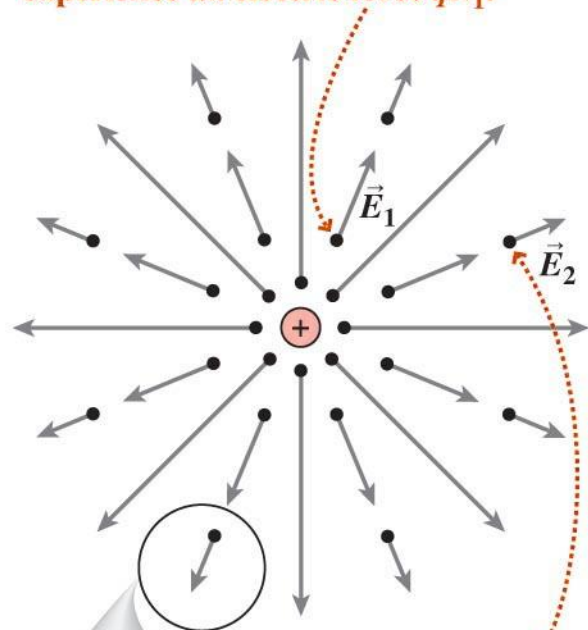
An electrostatic force acts on the charge

$$\underline{F} = q \underline{E}$$

in which  $q$  is the charge of the particle (including its sign) and  $\underline{E}$  is the electric field that the other particles have produced at the position of the particle

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \cdots = \sum_i \vec{E}_i = \sum_i \frac{kq_i}{r_i^2} \hat{r}_i \quad (20.4)$$

Right at this point the electric field is described by the vector  $\vec{E}_1$ . That means a point charge  $q$  placed here would experience an electric force  $q\vec{E}_1$ .



Over here, farther from the charge producing the field, a point charge  $q$  would experience a weaker force  $q\vec{E}_2$  in a different direction.

The electric field is a continuous entity, so there are field vectors everywhere. We just can't draw them all.

(b)

