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making physics matter

Age 7-11 years

Research cards

Leonardo da Vinci

credit: LACMA

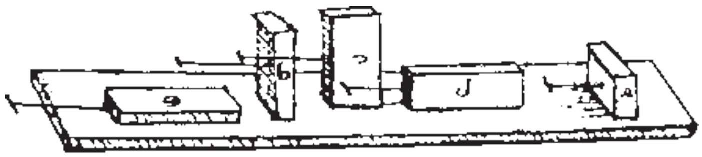
About

Leonardo da Vinci was born in Tuscany, Italy in 1452. He was an inventor, artist, mathematician and scientist – in fact Da Vinci was interested in everything! Historians describe Da Vinci as a 'universal genius' with an 'unquenchable curiosity' and a 'feverishly inventive imagination'. He lived until 1519, when he died of a stroke while living in France.

Working scientifically

Leonardo da Vinci was always inventing machines – particularly ones that could be used in battle or to protect cities. While working in Venice, he invented a mechanical knight, a steam cannon, hydraulic pumps and crank mechanisms. He also had a fascination with flight and, after carefully observing how birds fly and their anatomy (body structure), he designed flying machines and the first parachute.

When building and testing his machine designs, Da Vinci began to realise how important the force of friction was. Although previous scientists had known about it, no one had ever planned and carried out tests on friction. Da Vinci asked questions about how the force of friction could be reduced (or increased) in his machines. He made predictions about what factors affect the size of the frictional forces and carried out simple tests to see if his predictions were correct.



Da Vinci made measurements and collected data to compare the force of friction when different surfaces were sliding over each other. He looked for patterns in his data and came up with two laws of friction.

1. The area in contact (touching) has no effect on the size of the frictional force.
2. If the weight of an object is doubled, the frictional force doubles.

Da Vinci used scientific ideas to explain his observations. He said that friction was caused by the roughness of a material, with smoother materials having smaller frictional forces between them. He used this improved understanding to invent different types of anti-friction bearings to make the moving parts in his machines function better. Da Vinci never published any of his work, he just recorded all of his ideas and experiments in his own journals.

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Guillaume Amontons

credit: Public domain

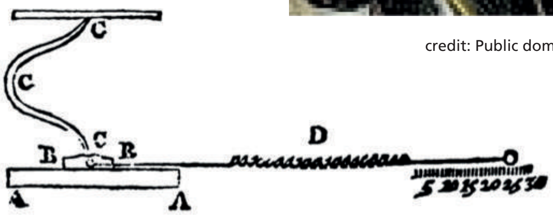

Figure 1.5: Amontons' sketch of his apparatus for friction experiments. The spring D measures the friction force during the sliding process between materials A and B. Spring C adjusts the normal force. (From[1])

About

Guillaume Amontons was born in Paris, France in 1663. He became an inventor of scientific measuring instruments and a physicist. He was one of the pioneers in studying the force of friction. Amontons died in Paris in 1705 when he was 42 years old.

Working scientifically

As a boy, Guillaume Amontons lost his hearing, which made it difficult for him at school. He didn't go to university, instead he spent most of his time studying mathematics, physics and astronomy by reading books. He was very curious about the world around him and was always asking great questions about how things worked.

Amontons was frustrated that instruments for making scientific measurements were not very accurate; he improved the design of barometers (for measuring air pressure), hygrometers (for measuring air humidity – how damp it is) and thermometers (for measuring temperature). These measuring instruments were used by sailors so that they could monitor the weather conditions. He also invented a water clock for keeping time during sea voyages.

Amontons came across Leonardo da Vinci's old notebooks and became fascinated by them. Da Vinci's experiments and ideas inspired Amontons to investigate and learn more. He carried out tests with different materials that had rough and smooth surfaces, finding out how steep the slope needed to be for an object to slide down it. He measured angles, recorded his data and looked for patterns. He repeated his experiments again and again to make sure he got the most accurate results he could.

Amontons came up with his own set of laws of friction, based on Da Vinci's.

1. The force of friction increases if the weight of a moving object increases.
2. The force of friction is not affected by the area in contact (touching) between a moving object and a surface.
3. Friction between rolling surfaces is not the same as for sliding surfaces.

Amontons thought that frictional forces existed because objects had to do work either to lift one surface over the roughness of another, or to squash/wear out the other surface.

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Leonhard Euler

About

Leonhard Euler was born in Basel, Switzerland in 1707. He was a mathematician, physicist and engineer. He had 13 children and over his life managed to write almost 900 books. Euler lost his sight in later life but still continued to work until he died in 1783 in St Petersburg, Russia.

images: wikipedia, creative commons

Working scientifically

Euler studied the motion of a block on a sloping surface. He thought carefully about the sliding movement and he created a model in his mind to help him understand what was happening.

Euler imagined that the surface of the block and the sloping surface both had interlocking zig-zag ridges (see Euler's diagram). He thought the force of gravity was trying to pull the block down the slope and discovered that there was a difference between the force of friction when the block was stationary and when it was moving. Euler gave the two types of friction different names, 'static friction' when an object was still and 'kinetic friction' when an object was moving.

Euler planned and carried out simple tests, sliding blocks down a slope. He measured the angle of the slope when the block first began to slide, and he also made measurements to investigate how the block sped up (accelerated) while it was sliding down the slope.

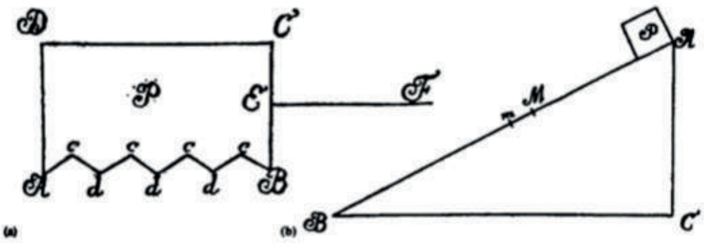

Image credit – E Mayer, 2002 – [Nanoscience friction and Rheology on nanometre scale]

Euler collected lots of data by repeating his tests again and again. He used graphs and mathematics to look for patterns in his measurements. He found that there was a relationship between friction and the angle of the slope: The steeper the slope, the smaller the force of friction between the block and the slope. He also came to the conclusion that 'static friction' is always larger than 'kinetic friction'.

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Charles-Augustin de Coulomb

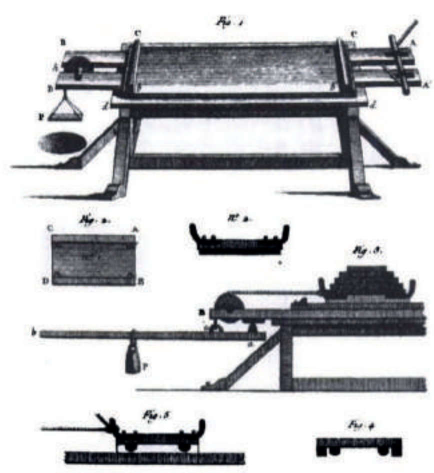
credit: Public domain

About

Charles-Augustin de Coulomb was born in Angolême, France in 1736. He was a military engineer and physicist. Coulomb is best known for his work understanding electricity, but he also did important work on friction. Coulomb died in Paris, in 1806.

Working scientifically

As a young man, Coulomb moved to Paris with his family, where he later studied mathematics at the Collège des Quatre-Nations. After graduating he enrolled in military school and became an engineer. For 20 years he travelled all over the world building military structures, including nine years spent on the island of Martinique in the West Indies, where he was in charge of building Fort Bourbon.



After falling ill with a fever, Coulomb returned to France where he used his mathematical skills to get a better understanding of architecture and building structures. He spent time working in shipyards researching the friction and stiffness of ropes. This was where he became aware of the work of Guillaume Amontons on frictional forces.

Amontons' work inspired Coulomb to plan and carry out further experiments on sliding friction. He was particularly curious to find the answer to the question: 'does the speed of a sliding object affect the force of friction that acts on it?'. Coulomb designed simple tests to measure the size of the frictional force when surfaces were sliding across each other at different speeds. He carried out tests and recorded his measurements, repeating his experiments to make sure that his results were reliable. After carefully analysing the data that he had collected, Coulomb came to the conclusion that 'the size of the frictional force does not depend on the speed of slipping'.

The friction experiments that Coulomb carried out in the shipyards led him to write the book Theorie des Machines Simples (the theory of simple machines). The scientific world thought that this book was excellent and rewarded Coulomb by awarding him a special science prize – the 'Grand Prix' from the Académie des Sciences in 1781.

When the French Revolution began, Coulomb, an aristocrat, had to leave Paris and retire to his country home in Blois.

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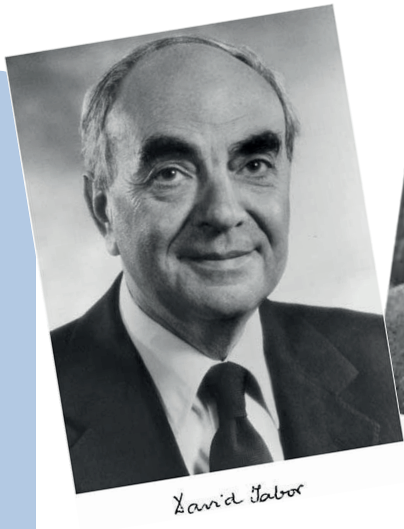
Research cards

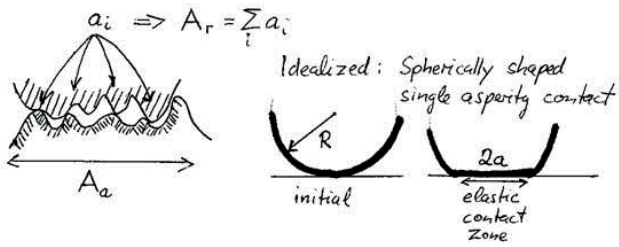
Philip Bowden and David Tabor

About

Philip Bowden was born in Australia in 1903, he went to university in Tasmania to study physics, eventually becoming a Doctor of Physics and moving to England to work at the University of Cambridge. It was there, at the famous Cavendish Laboratory, that he began working with David Tabor (born in London in 1913). Bowden and Tabor investigated the force of friction between surfaces on a microscopic scale – looking more closely at what was happening than any scientist before them. Bowden died in 1968, but Tabor continued their research for many more years until his death in 2005.



credit: Cambridge University



Working scientifically

Bowden and Tabor were both fascinated by the force of friction. They had studied the laws of Amontons and Coulomb but they really wanted to understand why those laws existed. Bowden and Tabor made very detailed and accurate observations of the surfaces of metals using special microscopes. They discovered that the actual area of contact between two sliding surfaces was much smaller than it appeared. When describing the contact between two rough surfaces (where tiny bumps are like mountains on a microscopic scale), Bowden said it was like "Austria turned upside down on top of Switzerland".

Bowden and Tabor explained that the true cause of friction was how the bumps and ridges on the surfaces touched each other (diagram) and that when the force pushing two surfaces together increases (due to a heavier object), more bumps and ridges come into contact, causing more friction.

Their new understanding of friction led them to research how lubrication could reduce frictional forces between surfaces. They carried out many experiments coating sheets of metal in different substances and then accurately measuring the force of friction between them when they were sliding. To make their tests fair, they kept the following factors the same: the area of the surfaces; the weight pressing on the surfaces; and the pushing force causing the surfaces to slide. They only changed one factor: the surface coating.

Bowden and Tabor found out that if you coat a hard surface in a soft metal, such as putting a layer of lead on top of brass, the friction becomes five or even 10 times less. This improved many engineering designs and, for example, as soon as the discovery was made, Australian engineers started using copper bearings coated in lead for all new aircraft.

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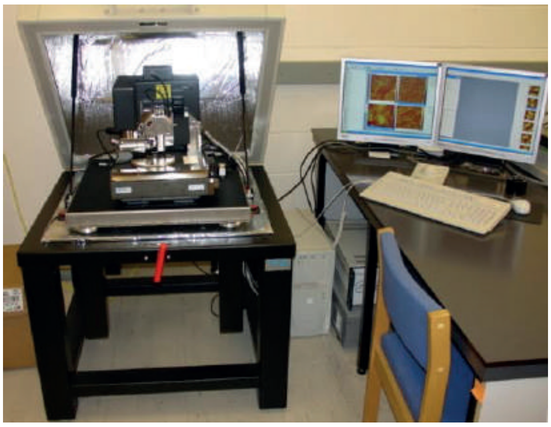
Atomic force microscope

About

The atomic force microscope (AFM) is a measurement tool that enables scientists to investigate objects that are more than a thousand times smaller than you can see using an ordinary microscope (which uses light and lenses). The AFM makes it possible to study how atoms (the tiny building blocks of matter) on the surface of objects interact with each other. It was invented in 1982 by the German physicist Gerd Binnig.

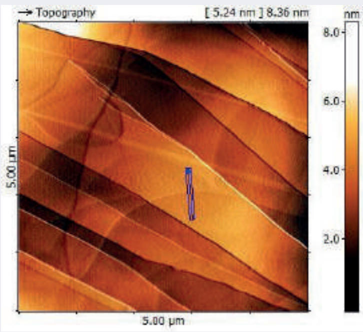


Credit: Zureks

Working scientifically

The AFM has a mechanical probe, which moves in a line a tiny distance above a surface, 'feeling' it and sending the data back to a computer. If this probe is moved slightly each time the surface is scanned, a 3D picture of the surface can be constructed.

The AFM can measure features smaller than one thousand millionth of a metre in size (0.000000001m) – scientists and mathematicians call this unit of measurement a nanometre. This means that scientists can now accurately measure the bumps and ridges on surfaces and determine the actual contact area of two surfaces rubbing against each other. They can group and classify materials based on the measurements and patterns they observe.



Credit: DME Scanning Probing Microscopes

Very tiny forces of attraction between atoms in materials can also be measured using an AFM, giving us an even better understanding of what causes the force of friction between materials.

Technology that is developed to research one area of science can often help us investigate other areas of science too. For example, in recent years, the AFM has been used to study biological cells and microorganisms at an atomic level.

Isabel Bennett has used the AFM at the London Centre for Nanotechnology while studying to become a Doctor of Biomedicine. She carefully observes bacteria cells and carries out tests to observe how antimicrobials (chemicals that kill germs) affect the bacteria cells over time. Using the AFM, she has taken amazing photographs of microorganisms and she also uses her data to print 3D models of the bacteria she studies.

Credit: UCL:i-senseEPSRC IRC

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Writing framework

Name .... Research team ....

Who or what are you researching?	
Where were they from/ where did this project take place?	
Between what years were they alive/when did this project take place?	
What was most significant about the discovery/project?	
What working scientifically skills did the scientist(s) show in making their discovery/ working on the project?	
Why was this discovery/ project important?	
What other interesting facts did you discover about this person or project?	
What else would you like to know about this person or project?	