How should we begin teaching Physics today? Force or Field first?

Understanding how the same kind of objects interact with each other, initially began with studying the **Forces** they exert on each other. The force applied by "mass on mass," "charge on charge," and "magnet on magnet." Establishing the fundamental laws of physics started with experimental methods of measuring the force applied by one object on another of a similar kind. One of the key figures and the first in this exploration was Newton, who laid the foundation for Dynamics in Physics.

a. Newton discovered and described the **gravitational force**, which is the force of attraction between two masses. He expressed this concept with a famous equation:

$$F = \frac{Gm_1m_2}{r^2} \qquad (1)$$

Where:

- F is the gravitational force in Newton (N),
- m_1 and m_2 are the object's masses in Kilogram (Kg),
- r center-to-center distance between the two objects in Meter (m), and
- $G = 6.67.10^{-11}$ in Nm^2/Kg^2, the **universal gravitational constant,** to balance the units and ensure F is in Newton (N).

b. Coulomb, similarly, demonstrated experimentally that the **electrostatic force** between two electric charges can be expressed as:

$$F = \frac{KQ_1Q_2}{r^2} \qquad (2)$$

Where:

- Q_1 and Q_2 are the electric charges of each object in Coulomb (C),
- r center-to-center distance between the two charges in Meter (m), and
- $K = 8.99.10^9 \frac{Nm^2}{C^2}$, the **Coulomb constant**, ensuring the system and units balance, so F is in N.

Note: Electric charge can be positive or negative. The interaction between like charges is repulsive, while opposite charges attract.

c. The magnetic force has been recognized in moving charges. Similar to those two natural forces above, the **magnetic force** between two moving electric charges could be expressed as:

$$F = \frac{K'Q_1V_1xQ_2V_2}{r^2} \qquad (3)$$

Where:

- Q_1V_1 and Q_2V_2 represent the two moving charges, in C.m/S
- r is the distance between the two vectors QV in meter (m), and
- $K' = 10^{-7}N.S^2/C^2$, is the balancing constant like the two other formulas.

This formulation is less commonly encountered in lectures because the force exerted by a moving charge on another is complex. The magnetic force was studied through the interaction of a natural magnet on a moving charge, in a wire carrying an electric current "I", or in a Cathode Ray Tube (CRT).

The complexity arises from the interplay of the charge signs and the directions of motion, which require consideration of vector products and the right-hand rule to determine the force's direction.

Why exploring the concept of "Field"?

This discussion does not aim to teach Gravity, Electrostatics, or Magnetism but to emphasize the challenges faced by physicists of the past in understanding these complex subjects. During that time, the concept of a **Field** was not well understood. Despite this, physicists relied on a systematic research approach: **Observation, Hypothesis, Experimentation, Data Collection and Analysis, and Conclusion**. This method helped them build a reliable and solid understanding of forces like gravity, electrostatics, and magnetism.

Through their perseverance and structured approach, physicists overcame these challenges, achieving remarkable progress and laying the groundwork for modern physics.

Part 1.

a. While measuring the gravitational force applied to a mass on the Earth's surface, the Newton formula "$F = mg$" has been experimentally verified, where $g = 9.8\ (\frac{N}{Kg})$ represents the Earth's gravity. Using Newton's Second Law, this becomes the acceleration due to Earth's gravity in Free Fall.

$$F_{net} = mg = ma$$

It follows that: $a = g\ \left(\frac{N}{kg}\right)$ where g is expressed as: $9.8\ (\frac{m}{s^2})$

About 100 years later, Cavendish's experiment provided empirical validation for Newton's formula (1) despite the challenges posed by the very small value of G. Cavendish determined: $G = 6.67.10^{-11}\frac{Nm^2}{Kg^2}$

Using G, the Earth's mass: $M = 5.98.10^{24}Kg$, and the Earth radius $R = 6.38.10^6 m$, the value of g can be calculated as: $g = 9.799$, which is very close to the value of $g = 9.8\ (\frac{N}{Kg})$.

b. Meanwhile, Coulomb introduced the formula for electric force, which was much easier to verify experimentally. To align the measurements and units, he used a constant:

$$K = 8.99.10^9\ \frac{Nm^2}{C^2}$$

Later, this constant was expressed as: $K = \frac{1}{4\pi\varepsilon_0}$

Note: ε_0 is the permittivity of the space (vacuum), which describes how an electric **field** propagates through space. Its value is:

$$\varepsilon_0 = 8.85.10^{-12}\frac{C^2}{Nm^2}$$

Later, Gauss explained electric force by considering that a single charge Q (source particle at the centre) produces an electric field around itself. This field then exerts a force on other charges in space, similar to how the Earth's mass M produces a gravitational field outside of itself and attracts all masses around.

Using the relation $F = Eq$, Gauss further defined the electric field as:

$$E = \frac{F}{q}\ in\ (\frac{N}{C})$$

Where q is the charge of the object in the field $\boldsymbol{E}$.

Gauss postulated that charge Q spreads an **electric flux φ** uniformly around itself, defined as: $\varphi = Q/\varepsilon_0$
Then Electric field ***E*** generated by the charge Q at a distance r is given by:

$$E = \frac{kQ}{r^2} = \frac{Q}{4\pi\varepsilon_0 r^2} = \frac{\varphi}{4\pi r^2}$$

c. The approach to understanding the Magnetic Field was more challenging because magnetic effects only arise when an electric charge is in motion. Unlike mass or electric charges, we cannot define a **Particle Magnet,** which makes the formulation of Magnetic Force more complex.
It has been demonstrated that a moving charge Q in (C) with velocity V (m/s), is deflected by a magnet.
Lorentz established the relationship between the forces applied by a magnetic field ***B*** in Tesla (T) on a moving charge qv:

$$F = qvxB \qquad \text{Lorentz law}$$

Here F, v, and B are vectors and the multiplication is a "Cross product (x)". The direction of the force can be found using the "right-hand rule".
Biot-Savart described the magnetic field B produced by a moving charge QV as:

$$B = \frac{K'QV}{r^2} = \frac{\mu_0 QV}{4\pi r^2}$$

Where:

- B is the magnetic field intensity in Tesla $(\mathrm{T = N.S/(C.m)\ or\ = N/(A.m)})$
- $K' = 10^{-7}N.\frac{S^2}{C^2} = T.m.S/C$ is the constant balancing of the system and units in a vacuum
- $\mu_0 = 4\pi x10^{-7}N.S^2/C^2$ is the "Vacuum Permeability"

Note: The Lorentz law could be presented as follows:

$$F = IlxB$$

This formula is widely used and has a variety of applications, it expresses the force applied by a magnetic field B in Tesla on a conductor with the length l in Meters carrying current I in Amps (A).
Considering Il substitutes qv, $(= It \,\&\, v = l/t)$ and since this is a vector product, the order of vectors must not be switched; otherwise, the conventional Right-Hand Rule won't apply.

Similar to gravitational and electrostatic forces, the magnetic force between two moving electric charges can be expressed as:

$$F = \frac{K' Q_1V_1xQ_2V_2}{r^2} = \frac{\mu_0 Q_1V_1xQ_2V_2}{4\pi r^2} \qquad (3)$$

Where:

- $Q_1V_1\ and\ Q_2V_2$ are two vectors representing moving charges, and
- r represents the distance between two vectors in meters.

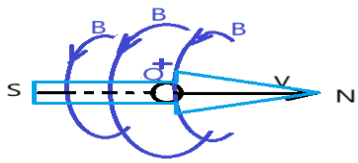
Note: Natural magnets exist due to the orbital motion of electrons around the nucleus, a phenomenon described by the "Bohr Magneton(μ_B)". In most elements, the magnetic properties of electron pairs cancel out because they spin in opposite directions.
Note: It can be easily concluded that:

$$\varepsilon_0\mu_0 = \frac{K}{K'} = 4\pi x10^{-7}\frac{N.S^2}{C^2}.8.85.10^{-12}\frac{C^2}{Nm^2}$$

$$= 1.11.10^{-17}(\frac{S^2}{m^2}) = \frac{1}{8.99.10^{16}}(\frac{S^2}{m^2}) = \frac{1}{c^2}$$

The complexity of the magnetic field arises from the fact that the magnetic field vector ***B*** is tangent to circles called the Field Line, close circles in the plane perpendicular to the velocity vector at the center. Depending on the direction of motion and the sign of charge, the direction of the magnetic field can be determined using the right-hand rule known as North and South Pole.

Q^+ Moving to the right, B out of the Page



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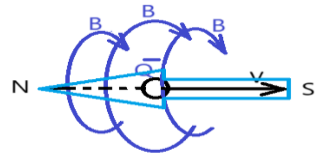


This complexity makes visualizing the interaction between two moving particles in space challenging. Magnetic forces have been observed in various contexts, such as the force exerted by a natural magnet on a conductor carrying an electric current or the behaviour of moving charges in Cathodes, Ray Tubes (CRTs), and applications like electric motors and power generators.
For this reason, textbooks often present multiple formulas beyond equation (3). However, the primary goal of this paper is to explore a “Unified theory of the field.”

Part 2:
All these forces are proportional to the sizes or magnitudes of the interacting objects and inversely proportional to the square of their center-to-center distance. At that time, scientists did not have a clear understanding of the concept of a field as we do today, they recognized the phenomena primarily through the observable interaction between similar entities, which they described as **Force**. The necessity of fixing one of the objects as the primary or source in some cases led physicists to define Field by dividing the force applied to the object by the corresponding quantity, like:

- $g = \frac{F}{m}$; for gravitational field,
- $E = \frac{F}{q}$; for electric field,
- $B = \frac{F}{qv}$; for magnetic field.

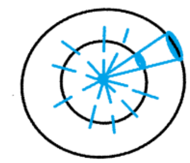
After this long introduction, it’s time to discuss the purpose of this paper.
Based on many years of teaching Physics, I realized that in the 20th century (now 21st), everybody knows that electromagnetic fields, Radio, TV, Mobile phones, and specifically internet signals are everywhere in space just because there is a source, a transmitter somewhere that emits the signal, and then users with a decent receiver collect the signal anywhere they are, just like one see the light because the sun shines somewhere.

Why today do we explain the interaction of two objects in an experimental way, by studying the Force but not just using simple reasoning and defining the Field made by an object first then the Force?

Let’s assume we go into space far from <u>anything</u>, any object or material while taking six different things with us: a Light bulb, a speaker, a pot of smelly food, a massive ball, an electric charge, and a magnet. Assuming that space is <u>empty, uniform, homogeneous, and isotropic with no obstacles or sources</u> interfering. By turning on the light bulb with output power P watts, the light will propagate uniformly in all directions at the same speed. To determine the light intensity at any point in the surrounding space at a distance r from the bulb, and considering the distribution depends only on the Geometry of Space.

Clearly the light spreads out evenly over a spherical surface with a radius r. The light intensity "***I***" at any point around on unit area, is calculated by dividing the power P by the surface area of the sphere:

$$I = \frac{P}{4\pi r^2} \text{ in watts /m}^2$$



Knowing the surface area of a sphere with the radius r is equal to: $4\pi r^2$

The sound energy emitted from the speaker or the spreading smell from the food pot will follow the same rule, the <u>density of the electric field flux</u> will also be:

$$\frac{Enegy}{4\pi r^2}$$

Those properties were easy to sense since we have eyes, ears, and noes. The human body lacks natural sensors for phenomena like gravity, electric, or magnetic fields. This lack of direct perception initially made it challenging to approach these problems. Scientists struggled to conceptualize that objects with mass, charge, or magnetic properties could extend their influence through space and produce a **flux**, the flow of a specific quantity across a defined area in space, similar to other detectable phenomena.

Fortunately, these days even a beginner in physics can easily write the 3 fundamental laws of Physics just by understanding the example of a "Light Bulb" and the distribution of light or sound in space.

So they can rule: **If an object exists at a point in space, its presence inevitably causes changes in the surrounding space, otherwise, the object would be null, zero, or non-existent**. This change in the surrounding space is what we define as a **field** created by the object.

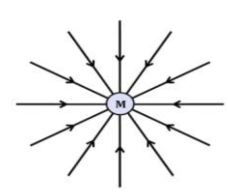
Now let's try all over again to write these 3 fundamental Physics laws based on our understanding:

1. We take out the Mass "M" and place it on a point in space, this produces a change in space, we will call it **Gravity** which is proportional to:

$$\frac{M}{4\pi r^2}$$

It is clear that here too, we need a constant to balance the measures and units exactly like Newton. Just remember that Newton didn't start this way, so in his formula, "4π" is not absent but just included in ***G***. Therefore we can write the gravitational field:

$$g = \frac{GM}{r^2}$$

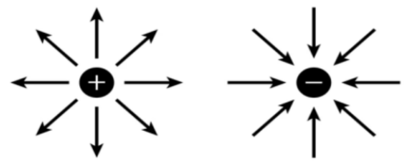


2. Now take out a Charged Object "Q" and place it at a point in space, this produces a change in space, we will call it the Electric field "***E***" which is proportional to:

$$\frac{Q}{4\pi r^2}$$

A constant "ε_0" to balance the measures and units exactly here is also needed.
Therefore we can write the Electric field as the <u>density of the electric field flux</u>:

$$E = \frac{Q}{4\pi \varepsilon_0 r^2}$$



3. Now take a Charge and shoot it in space, "QV" produces a change in space, so we will call it a Magnetic field "***B***" proportional to:

$$\frac{QV}{4\pi r^2}$$

A constant "μ_0" to balance the measures and units exactly, here is also needed.
Therefore we can write the Magnetic field as the <u>density of the magnetic field flux</u>:

$$B = \frac{\mu_0 QV}{4\pi r^2}$$

Just remember magnetic line field are close loops.

Therefore, the 3 **Field** formulas were easily stabilized directly, now it's time to talk about **Force**.
If an object is exposed to a field generated by a similar type of object at its location, experiences "Force," which makes it accelerate (Newton's Law of Motion).

For example, Gravitational Field g_1 produced by a mass "m_1" (source) applies a Force to mass "m_2" (object) at a distance r (center-to-center), according to:

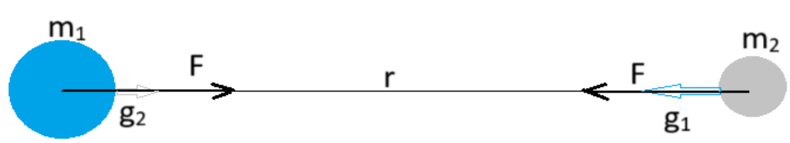
$$F = m_2 g_1 = \frac{G m_1 m_2}{r^2}$$

Inversely, the field produced by the object m_2 at the position of the source $g_2$using:

$$g_2 = \frac{G m_2}{r^2}$$

Then the attraction force applied by the object on the source will be:

$$F = m_1 g_2 = \frac{G m_2 m_1}{r^2}$$



We can see the consistency of Newton's law and easily realize that the force is a mutual interaction between two similar objects, this means we can switch the role of the source and the object

This is the same as equation (1), proving Newton's 3rd Law meanwhile, which says the force applied by mass m_1 on m_2, is equal opposite to the force applied by m_2 on m_1.

Electric Field produced by a charge “Q” (source) applies a Force to charge “q” (object) at a distance r, according to:

$$F = qE = \frac{KQq}{r^2}$$

This relation is also mutual, object 1 on 2 or vice versa, and the force can be attractive or repulsive depending on the signs of charges.
Magnetic Field produced by a moving charge “QV” (source) apply a Force to another moving charge “qv” (object) at a distance r, according to:

$$F = qv\text{x}B = \frac{K'QVxqv}{r^2}$$

Note that the sing “x” stands for the Vector Product of the two vectors $QV\ and\ qv$ and the force is normal to the page made by those two vectors in the direction following Right-Hand-Rule.
In this case, the magnetic force is also a mutual relation between objects 1 and 2 or vice versa, and it can be attractive or repulsive depending on the signs of charges and the direction of their motion.
In the case of **gravity** and electric fields, the Field, the Force, and therefore the motion of the objects are all aligned with the **Lines of Field** or **Force Lines,** they are straight lines, which means the object can move towards or away relative to the source straight. Although the magnetic field lines are curved (Close Loops), the force or the motion path is circular in constant circumstances.
Note: It is clear, **that** all these formulas require a constant to adjust units and ensure proper balance within the system.

Conclusion:

Newton, Coulomb, and Lorentz described forces because they were easier to measure experimentally, with no initial concept of fields. From a modern perspective, starting with the more fundamental idea of fields better clarifies the interaction between two objects known as forces.
Therefore, with all due respect for the hard work of these scientists and the lifetime challenges they faced, it is highly recommended that when teaching the three most fundamental concepts and formulas in physics, we start by explaining the **Field** created in space by the existence of an object. This approach aligns with modern understanding and common sense. We clarify that the field created by an object acts on another similar object because both produce the same type of field in the same way. This action reaction between two object is called Force. This approach underscores that force arises from the interaction between two fields of the same type or a field on an object of the same kind.
Then we extend these rules to different applications, solve all kinds of problems about field and force, and answer all existing questions.