Comparison between Electromotive Force and Electric Potential Difference

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Abstract: The aim of this review is to compare electromotive force and electric potential and to find out similarities and some major differences between them. We found that emf is a complex concept for elementary physics' students and has serious problems in its understanding, while the concept of Pds is relatively easy. EMF keeps potential difference while potential difference causes current to flow. Moreover, some major differences between emf and electrical potential are highlighted like EMF is cause and potential difference is effect, Electromotive force is the amount of energy that is given to one coulomb of charge to go around whole circuit while Potential difference is the amount of energy used by one coulomb of charge. That is why they are not synonyms words. Teachers and students should be careful in their usage. Because of the name, some people think electromotive force as a force, actually it is not a force but it is the energy that is used to maintain a constant potential difference between two points. Emf shows how much energy is supplied to the circuit to move one coulomb of charge across the whole circuit. Emf is greater than the potential difference between any two points. Potential difference is always less than the maximum value of emf when the battery is fully charged. Although electromotive force and potential difference has some similarities like they have same SI unit(volt) and their dimension is same $[M^1L^2T^{-3}I^{-1}]$, potential difference is the key to how current flows, but there are many differences that I have highlighted in this article.

Keywords: Electromotive force, Electrical potential, Electrical potential difference, differences between electromotive force and electric potential differences.

1. Introduction

What is a Voltage?

We know that water flows from high pressure to low pressure just as air molecules flow from high pressure to low pressure. Similarly, electric charges flow from a place where the density of charges is high, to a place where the density of charges is low. To flow to a higher potential, some work must be done. This work done on the charge is called the electric potential and is represented by v, measured in volts.

Voltage is the potential difference between two points which causes current to flow. It is the amount of energy per unit charge while moving between two points. The energy required to move a unit charge from one point to another is known as voltage. In other words, voltage is defined as the difference between electric potentials, and is denoted by a capital V. its unit is volt, which is measured by a voltmeter. One volt is equal to the electric potential at which one ampere of current consumes one watt of power between two conducting points. **Or** a volt is the potential difference between two points that moves one joule of energy for each coulomb of charge.

What is EMF?

EMF or electromotive force is the amount of energy delivered by the source(battery) to the charge. It generates voltage within active battery sources and gives energy in joules per coulomb of charge. EMF is denoted by ε and it is measures in volt. EMF is the maximum potential difference between two points of the battery when no current is flowing from the source in open circuit condition. At first glance the name EMF implies that it is a force that causes current to flow. But this is not correct because it is not a force it is energy provided to charge by some active devices like batteries. Electromotive force is the amount of energy that is given to each coulomb of charge to go around whole circuit while Potential difference is the amount of energy used by one coulomb of charge.

Potential difference is severely the difference in electrostatic potential due to electric charges and is subjected to their positions and quantities. When charges move (current flows), we describe the electrostatic potential difference as an instantaneous arrangement of moving charges. An electric field between any two points has an emf which is given by. Now the electric field may be due to the location of the charges (it may be an electrostatic field) or it may be due to electromagnetic induction (in which case it is an electrodynamic field). Such a produced field does not result in a potential difference in the absence of matter. The fundamental difference between p.d and emf is often hidden in the engineering literature by the unselective use of the voltage term for both concepts. Particularly in the case of an electrostatic field the name of the potential gradient is strongly applicable to the intensity of electric field E(r) but it should not be used to express the intensity of the generated electrodynamic field. The only term that can be used in all cases is emf gradient because all electric fields have an electromotive force **(Page, 1977)**

The battery is an integral part of the circuit, where a series of non-conservative actions take place through which energy is transferred to charge. These actions are expressed as work done per unit charge or electrical energy per unit charge to produce and maintain an electric potential difference that allows the flow of electric current. Thus, the emf depends on the work done by the non-Columbic force to move the charge between the terminals inside the battery; The potential difference depends on the work done by the Columbic field to move one unit of charge between the terminals outside the battery.

Many students confuse emf and potential differences, and they do not have a conceptual understanding of emf. The majority of students do not understand that the concept of electromotive force is a quantity that measures the work done per unit charge by non-conservative forces to provide electrical potential energy to the entire circuit (both external and internal to the battery). The standard introductory course introduces electric potential in the chapters on electrostatics. Attention is usually given to calculating the potential function for various discrete and continuous charge distribution .Students have to understand that emf and potential difference are dissimilar concepts, most likely through considering work and energy. In summary, electromotive force is a quantity that measures the energy transfer (from battery to charges within the circuit) related to a non-conservative field **(Garzón et al., 2014).**

Electric potential is the “amount of energy (or work) per unit of charge required to move that charge from a reference point to another point inside the electric field”. On the other hand, the electromotive force is properly described as the “amount of energy (or work) per unit of charge that is reversibly converted by a generator (electric field) into electrical energy by moving a charge from a reference point to another point.

The generator may be regarded as an “electron pump”. The crucial difference between those two concepts is that “reversibility” here requires the generator to be at an open circuit or no load conditions. This means that the actual value of electromotive force is obtained only when the generator is at the limit condition of not operating at all or at a state of a partial equilibrium6 with its surroundings (no net change) that is set by forcibly counteracting the spontaneity of the electrochemical reaction. This is not the state of chemical equilibrium that the reaction will eventually reach after enough current has passed through the cell to change the concentrations (activities) of the cell components **(Da Silva Rodrigues et al., 2018).**

(Zuza et al., 2016) relate emf to the working of a Van de Graaff generator, where the work done on a charge by a mechanical force causes charge separation, resulting in electric potential energy. (The conversion to thermal energy has been neglected). In a battery, the chemical ‘work’ or chemical potential energy is converted to thermal and electric potential energy. In electromagnetic induction, the electric current is induced in a ring located in a varying magnetic field. In this case, there is no charge separation in the ring, and hence there is no electric potential energy. The work done by the induced electric field is converted to thermal energy (the so-called Ohmic losses). In dc circuits a series of non-electrostatic electrical actions take place in the battery, through which energy is delivered to the charges. Emf measures the work carried out by non-conservative forces within the battery as it separates charges to generate a potential difference; potential difference measures the work done on the charges by conservative forces as they move from one point to another in a circuit.

2.Significance Of The Study

Humans have studied the phenomena of nature and are still busy studying them for the convenience of their lives. We know the different forms of energy and also the fact that one form of energy can be converted into another form. Electricity is a form of energy that has revolutionized human life. The emf source acts as a charge pump, moving negative charges from the positive terminal to the negative terminal to maintain the potential difference. The electromotive force increases the charges' potential energy and therefore the charges' electric potential.

Since human life is highly dependent on electricity, research involving EMF is important for the development of electrical technology. Electromotive force is defined as the electrical potential produced by electrochemical batteries or by changing magnetic fields. EMF is a commonly used abbreviation for electromotive force. A generator or battery (source of electromotive force) is used to convert energy from one form to another.

3.Review Of Related Studies

In terms of science emf is a broad concept. It is used for describing a large range of phenomena **(Zuza *et al*., 2016).** Electromotive force is crucial issue for chemical reactions and electrochemistry. Thus, it allows, interpretation of other thermo-dynamical quantities such as reaction free energy, entropy, and activity coefficients. Therefore, it is important to present the concept of electromotive force free of misunderstanding. It has been observed that undergraduate students and sometimes lecturers use the terms electromotive force and electric potential interchangeably. This misconception may be due to the fact that both electromotive force and electric potential are practically measured via an instrument called voltmeter. If teachers and lecturers fail to clarify the differences between electric motive force and electric potential, then students will not be able to distinguish between them and will use them same and the subject will remain dumb **(Da Silva Rodrigues *et al*., 2018).** Some lecturers have difficulty, using the concept of electric potential when they are explaining electric circuits. Moreover, a large number of teachers are not able to differentiate electromotive force from electric potential **(Garzón *et al*., 2014).** Most studies in physics are conducted regarding students' problems with the concepts of physics. Therefore, Students' understanding of physics' concepts is considered one of significant aspect of teaching. Knowing that which concepts and theories students can learn well, and with which of them they have difficulty, could further improve teaching and curriculum development. **(Zuza *et al*., 2016**).

Potential measures the capacity of a system to do work. Let's take a simple example from mechanics: by lifting a weight, its potential energy increases. When the weight is moved downwards, the potential energy is converted into kinetic energy. The electric potential V is the line integral of the electric field along a path from a point of origin to a given position: (Boettcher et al., 2021).

$$V = -\int \boldsymbol{E}\,dl$$

All phenomena of electromagnetic fields are expressed by Maxwell's equations. But the resulting phases are significantly different depending on field frequency (between high and low frequency). At high frequencies, electric and magnetic fields are propagated in space. This characteristic is called electromagnetic waves. It hardly appears for a low frequency, where we can treat electric and magnetic fields separately.If the magnetic field is absent or constant with time, induction is caused only by an external voltage (charge) that changes with time. This induction is called 'electrostatic induction', and is expressed by the following equation:

$$rot\ \boldsymbol{E} = \boldsymbol{0}$$

This means that the electric field is given by a scalar potential. The generated electric field then produces a current density that is related to the conductivity σ as follows (Takuma et al., 2006).

$$\boldsymbol{J} = \boldsymbol{\sigma}\ \boldsymbol{E}$$

Any system of electric charges produces an electric field E, at all points in space.

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

It is commonly easy to specify the electric potential than the electric field because the potential is not dependent on the physical geometry (locations and sizes of conductors) of a given system. The connection between V and E can be calculated without trouble in a few systems(Tenforde & Kaune, 1987).

$$V = \frac{E}{d}$$

The emf of cell decreases with increase in temperature.(Mikula, 2007) So Every chemist and materials scientist must be acquainted with electromotive force (EMF) measurements (Mikula, 2007) If there is a temperature difference, an electromotive force is always produced, even in non-metallic materials (Gerasimov, 2020)

In figure below there is a dry cell, in a dry cell chemical energy (other forms of energy) is converted into electrical energy. If we have 9 volt emf, what does that means? this means that 9J of chemical energy has been converted into electrical energy and this energy is supplied to the circuit to carry one coulomb of charge across the whole circuit from start to end. The more work is done , the faster the charge move and shows high current. Emf shows how much energy is supplied to the circuit to move one coulomb of charge across the whole circuit.

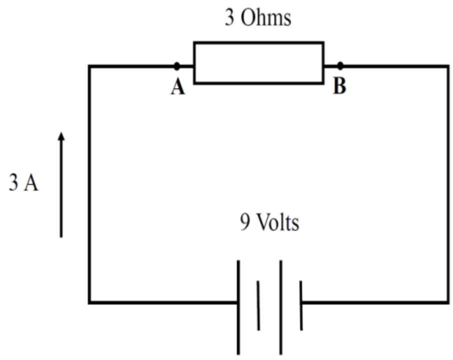

Figure 1: There is an external resistor between the two points A and B and the electrical energy in this resistor is converted into other forms of energy. So there is a potential difference between A and B because current flows through it.

The potential difference at the two poles of battery terminals is perhaps less than its EMF. Kirchhoff‛s second law tells us that around any closed circuit the sum of the EMFs(, equals the sum of the PDS (V) (Rose-Innes, 1985):

$$\varepsilon_1 + \varepsilon_2 + \cdots = V_1 + V_2 + \cdots$$

but if we cannot distinguish between PDs and EMFs, how do we know on which side of the equation to put any particular voltage? For example, is the voltage across an inductor a PD or an EMF? Every source of emf has internal resistance(r), so when it delivers current (I), the PD (V) between their output terminals will be less than the emf (ε)by the potential drop produced across the internal resistance by the current (I), (Rose-Innes, 1985).

$$V = \varepsilon - Ir$$

From the studies that I have done, I have found that there are some similarities between electromotive and potential difference that I highlighted.

Dimension of electromotive force (ε) is

$$[M^1L^2T^{-3}I^{-1}]$$

Where M is mass, L is length, T is time, I is current. We will try to find this dimension of emf.

Electromotive force is equal to work done by a unit charge.

Mathematically,

$$[\varepsilon] = [w] \times [q]^{-1}$$

Dimension of work is equal to $[w] = [M^1L^2T^{-2}]$ and charge is equal to current into time, so dimension of charge is $[I^1T^1]$.

Therefore,

$$[\varepsilon] = [M^1L^2T^{-2}].[I^1T^1]^{-1} = [M^1L^2T^{-3}I^{-1}]$$

Dimension of potential difference (ΔV) is

$$[M^1L^2T^{-3}I^{-1}]$$

From the definition, p.d (ΔV) is,

$$[\Delta V] = [w] \times [q]^{-1}$$

so

$$[\Delta V] = [M^1L^2T^{-2}].[I^1T^1]^{-1} = [M^1L^2T^{-3}I^{-1}]$$

The results of the previous studies regarding emf and pds have been compared. In science, we generally use electric potential difference instead of electric potential. For potential difference, there is a change in electrical energy into other forms of energy. For emf, it converts other forms of energy such as light energy, mechanical, thermal energy, etc. into electrical energy.

Electromotive force basically is not a force. It is the total voltage induced by the source. It is the energy transfer to an electric circuit per unit of electric charge (one coulomb), and it is also measured in volts. You can also define emf as the potential difference across the terminals of a cell when it is not given any current as shown in figure (a) and the potential difference is across the resistor as shown in figure (b).

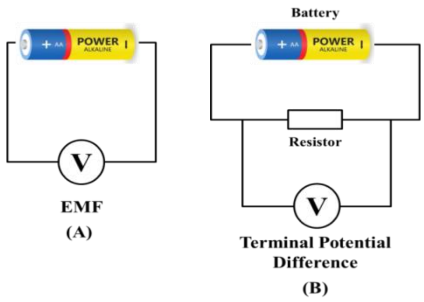

Figure 2 schematic comparisons between electromotive force and potential difference.

4.Objectives Of The Study

We want to compare electromotive force and electric potential difference,

- To find out Similarities between electromotive force and electric potential difference.
- To find out the key differences between electromotive force and electric potential difference.
- Every chemist and materials scientist must be acquainted with electromotive force (EMF) measurements
- The main object of this article has been to illustrate the contradictions between and ambiguities of the definitions which are commonly used.

5. Materials and Methods

In December 2022, literature reviews were collected on the different aspects of the Comparison between electromotive force and electric potential difference. The goal of this review study was to compare the electromotive force and electric potential and find out the major differences between them. However, for this library research, we collected articles that were published in the world's best journals and research has been done. Confined to internet searches using engines provided by Google throughout the world. The literature reviews were found from all published articles.

Table 1. Key difference between electromotive force and electric difference.

Basis for comparison	**Electromotive force**	**Potential difference**
Definition	It is the amount of energy supplied to one coulomb of charge.	The amount of energy used by one coulomb of charge in moving from one point to another.
Unit	Volt	Volt
Symbol	E	V
Resistance	Independent from the resistance of the circuit	Proportional to the resistance of the circuit
current	It transmits current throughout the circuit.	It transmits current between any two points.
Magnitude	Greater than the potential difference between any two points	Always less than the maximum value of emf when the battery is fully charged.
Variation	It remains constant	Does not remain constant.

Relation	Cause	Effect
Voltage	It is the maximum voltage that the battery can transfer	It is less than the maximum voltage that the cell can deliver.
Field	Causes in the magnetic, gravitational, and electric fields.	Induces only in electric field
energy	The source of emf gives energy into the circuit	Loss energy
Measuring instrument	EMF Meter	Voltmeter

Interpretation of table1.

Although many people use electromotive force and electric potential difference as synonym words, in fact they are not synonym because there are many differences as we mention.

7.Recommendations

- Electromotive force is not actually a force .electromotive force is the amount of energy delivered by the source (battery) to the charge. So it is important for teachers to explain it correctly to avoid misunderstandings.
- Teachers and students have to know the similarities and differences between electromotive force and potential differences.

8.Conclusion

This study concluded that emf is a complex concept for elementary physics students and they have serious problems in understanding it.

Although electromotive force and potential difference has some similarities like they have same SI unit(volt) and their dimension is same $[M^1L^2T^{-3}I^{-1}]$, but there are many differences as discuss above. so students and teachers as well as professionals should be cautious in their using. In this article we discussed some similarities and differences between electromotive force and electric potential difference. EMF keeps potential difference while potential difference causes current to flow.

Electromotive force and potential difference are not the same things. There are some similarities and differences between electromotive force and potential difference.

In brief,

Similarities between electromotive force and potential difference are as follows

- They have the same SI unit (volt)
- They have same dimension $[M^1L^2T^{-3}I^{-1}]$

Some differences between electromotive force and potential difference are as follows

- Electromotive force is $\varepsilon = V + Ir$ and potential difference is $V = IR$
- Electromotive force is greater than the potential difference except one case, that when source of emf (battery) is connected to the circuit and there is no external resistor.
- EMF is the cause and potential difference is the effect.
- Electric potential can be scalar and vector but Electromotive force is a scalar quantity.

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