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# What Might Aquinas Have Said?

The outcome of an experiment involving an electrical generator and a capacitor

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**Abstract**

We present a comparison of two forms of analysis applied to a simple experiment in electrodynamics. One uses contemporary physics and the other metaphysics as espoused by the 13th century scholar Thomas Aquinas. The aim is to illustrate an example of scientific abstraction and prediction of experimental outcomes, and the pitfalls of applying simple intuition.

**Keywords**: electric generator; electric motor; electric capacitor; electricity; electrodynamics; lines of force; magnetism; metaphysics; right hand rule; Thomas Aquinas.

## 1. Introduction

Our Aim was to try and formulate an argument that may hypothetically have been entered into by a scholar of the Middle Ages on being confronted by a device that was only to be discovered hundreds of years later. Imagine that the device was teleported to the desk of arguably the greatest recorded thinker of the Middle Ages, St. Thomas Aquinas [1]. What would he have predicted about its behaviour should he have been able to subject it to some simple experiments; the latter also being a notion not very familiar to most in those times? What was it like to reason when limited by the academic and intellectual resources available in the 13th Century? And lastly, is the metaphysical answer to '*The Question*' posed here, a neater, simpler and more befitting explanation than the one based merely on modern day physics? We hope you enjoy the trip back through time!

*PWK is an academic biophysical scientist who is intrigued by the question, "What constitutes a valid explanation for a natural phenomenon?" This question is one that is continually confronted, at least implicitly, in most academic activities. It is especially*

*apparent to those who work in a multidisciplinary School in a University. Molecular biologists appear to give their scientific explanations in common language while for physical and mathematical scientists most explanations are not considered to be complete without abstract mathematical formulae.*

*MVS is a barrister who has made a special study of the metaphysics espoused by Thomas Aquinas.*

What we present is a comparison of two forms of analysis applied to a simple experiment in electrodynamics.

Figure 1 is a photograph of the experimental set up, while Fig. 2 shows a modern abstract representation of the electrical circuit.

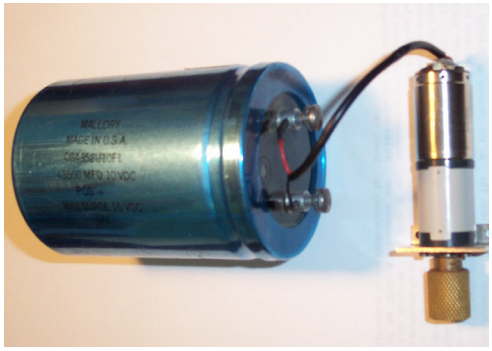

Fig. 1. The experimental apparatus. The large can is an electrolytic capacitor of 43.5 milli farads. The device on the right is an Escap motor (silver part) and its gear box, projecting from which is a shaft that has a knurled bronze knob mounted on it. The two wires from the motor are separately connected to the + and – poles of the capacitor. Turning the knurled knob makes the motor act as a generator, thus charging the capacitor. Once charged the capacitor in turn will act like a battery and hence drive the motor.

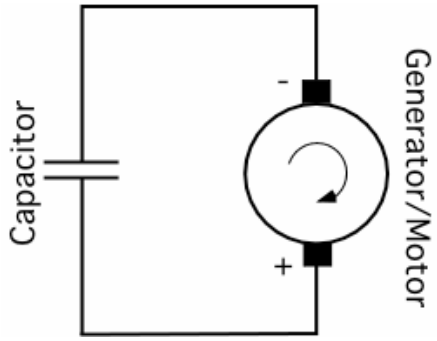


Fig. 2. Schematic electrical circuit pertaining to Fig. 1.

**2. The Equipment**

In Fig. 1 the aluminium can (diameter 76 mm and length 104 mm) is a modern electrolytic capacitor of 43.5 milli farads. The device on the right is an Escap (made in Switzerland) precision, direct-current (DC) electric motor. The knurled knob shown in the bottom right-hand corner of Fig. 1 is directly connected to the shaft of the grey cylindrical gearbox that, in turn, is mechanically linked to the shaft of the motor. The motor part is the silver cylinder. When the knurled knob is turned the motor acts as a DC generator. With a turning speed of ~100 rpm the electromotive force (EMF) generated is ~20 volts.

One of the wires from the motor is connected to the + pole of the capacitor and the other to the – pole.

### 3. The Experiment

The experiment involves *you* turning the knurled knob by hand, clockwise at ~100 rpm for ~10 seconds and then *you* releasing your hand. You then observe whether the knob continues to rotate in the same direction, or whether it reverses direction.

An additional simple experiment is to disconnect one of the wires from the capacitor as the motor is turning after you have released your hand. One observes that the knurled knob of the motor stops turning; but upon reconnecting the wire the motor proceeds to turn in the *same direction* as it was just prior to you disconnecting the wire.

Alternatively, if both wires are disconnected from the capacitor and reconnected in the swapped position, it is observed that the motor turns in the opposite direction.

Now, having had this description of what the experiment entails, let us ask you: "In what direction do you think the knurled knob will turn after you cease the forcible rotation of the knob?" [*The Question*]. In other words, will the knurled knob reverse its direction of rotation to spin anti-clockwise or continue in the same clockwise direction?

### 4. The Intellectual Milieu of Aquinas

What might St. Thomas Aquinas have predicted in response to this question? He was born in 1224/5, died in 1274, and was canonised in 1323. His metaphysical arguments are profound, but he antedated the discovery of electricity, and the phenomenon of magnetic induction by Michael Faraday [2], by more than 500 years. So he would have had no conception of an electrical capacitor, the use of copper wires to conduct electricity, the production of electricity by moving a conducting loop in the region of space near a magnet, or of an electrical potential causing the shaft of an electric motor to turn. On the other hand, supposing he was presented with the device shown in Fig. 1, and (without any sense of what the components did in the terms of our modern understanding) he may still have been able to deduce an answer to *The Question* posed above by the application of metaphysical reasoning. After all, he tackled some rather bold questions, such as "Whether God Exists?" and "Whether Essence and Existence Are the Same in God?" [1].

### 5. *The Question*…a Poll

PWK showed, or described in detail, the device in Fig. 1, to a large number of his academic colleagues. He posed *The Question* and sought their responses. Included amongst those who declared that the shaft with the knurled knob would *reverse* direction are Professors of Physics (including one who is Fellow of the Royal Society of London), Chemistry, Mathematics as well as many students in Biological and Physical sciences. Almost none of them answered correctly, that the knurled knob continues to rotate in the *same* direction!

Why should the behaviour of such a simple device be so counter intuitive to even very learned scholars of the 21st Century?

## 6. A Modern Day Explanation

This explanation appeals to a basic understanding (in the sense of being able to predict the outcome from simple experiments) of the behaviour of magnetic fields, and the concept of field lines [e.g., 3].

First we give some key definitions: (1) "A *magnetic field* is a region of space in which a moving electrical charge experiences a force by virtue of its motion, or a magnetic dipole whether static or moving experiences a torque". (2) The paths along which an imagined magnetic monopole would move are called lines of force (or isodynamic lines); but (3) there exist no magnetic monopoles *per se*.

In the previous paragraph we have used terms of which Aquinas had no knowledge: electrical charge, magnetic dipole, monopole, torque, and the implied notion of force. Notwithstanding this extra power in our linguistic arsenal our aim is to give an explanation of the fact that the knurled knob continues rotating in the same direction based on the minimum number of basic tenets.

The next notion that is 'common knowledge' today is (4) that "lines of force are conceived to repel each other". This was evocatively inspired by one of Ampere's experiments in which direct current passing in parallel wires fixed at either end, causes the wires to bow in towards each other; whereas when the current flows in an antiparallel manner the two wires bow out, away from each other [2]; in other words they are repelled from each other. Another suggestive observation of Ampere concerning lines of force is the arrangement of iron filings in apparent rings around a vertical current-carrying wire on a horizontal piece of cardboard that is pierced by the wire.

The result of Ampere's parallel-wires experiment leads to the 'right hand rule' that states that, (5) "If the fingers of the right hand wrap around the conductor, and the thumb of that hand points along the direction of the electric current, then the fingers curl in the direction of the lines of magnetic force". This implies that the lines of magnetic force pass around an isolated wire carrying an electric current; and, furthermore, the mutual repulsion of the lines suggests that they form a series of continuous rings around the wire in the manner of geological contour lines on a map around a volcano.

Finally, there is Lenz's law that states, (6) "The direction of current induced to flow in an electrical conductor, that is forced through a magnetic field, is such that the field induced by the current opposes the motion".

Armed with the above three rules and the other definitions, we can deduce an answer to *the* question. This is best done by reference to a diagram that captures the essential elements of an electrical generator (Fig. 3). The long cylinder denotes a section of conducting wire in the electrical circuit that incorporates the capacitor. **F** denotes the direction of forced motion of the wire that cuts the lines of force denoted by **B,** in the generator. The direction of the current is deduced from Lenz's law to be that denoted by **J**. (The three symbols are written in bold to indicate that they are vector quantities, having both magnitude and direction, a late $19^{th}$ century concept of Willard Gibbs.) In other words, the current flows in the indicated direction, because then the circular lines of force around the wire have a direction (specified by the right hand rule) such that the arrow(s) on the leading edge (left hand side) of the wire is in the same direction as the lines of force (arrows) of the magnetic field **B**; hence the two fields repel each other and

thus exert a force that opposes the motion indicated by the direction of **F (**thus satisfying Lenz's law**)**. The resulting current flow, leads to the charging of the capacitor.

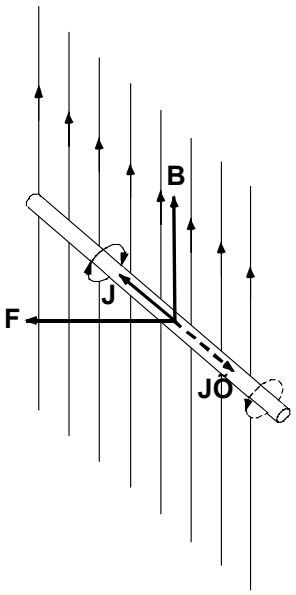


Fig. 3. Abstraction of what constitutes an electric DC generator and a DC motor. The main elements are a constant magnetic field, denoted by **B**; a conducting wire that carries the current **J,** or **J'**; a force **F** applied to the wire to make it pass through the magnetic field thus generating **J**; or in carrying the current **J'** to act as an electric motor. (From [5].)

Suppose that we now stop exerting the force **F**. Work is no longer done on the wire and current flows back down the wire in the direction indicated by the dashed arrow; this current is denoted by **J**. By the right hand rule the current induces a circular magnetic field that is in the opposite direction to what it was before. But, now the direction of the (dashed) arrow on the left-hand edge of the field loop around the wire, is pointing in the opposite direction to that of **B**; so, the wire will be drawn toward the left. In other words, the wire will continue to move to the left. Hence in a system where the wire is part of a rotating armature in a generator/motor, the rotation will continue in the same sense.

This is the full explanation. It does not appeal to the well known Fleming's left and right hand rules of electromagnetics, but does demand an acceptance of what is the fundamental 'essence' of an electric generator and an electric motor; specifically, it relies on acceptance of the fact that Fig. 3 contains all that is needed for the argument. The analysis does not stray into an argument that uses the vector cross product, and yet an explanation using that abstraction appeals to mathematicians and theoretical physicists. Hence there are many levels at which a modern day explanation of the outcome of the experiment could be made; but let us turn to a consideration of what Aquinas might have said and see if metaphysics could cut through these various 'local' theories and analyse the essence of the experimental set up, and thus provide an explanation for its behaviour.

**7. What Thomas Aquinas Might Have Said**

There is a problem regarding what Aquinas needs to be told about the apparatus in Fig. 1. We suggest that he would be shown a basic, or *elemental*, capacitor, consisting of two parallel brass plates supported on glass brackets and separated by a small distance. And he would be told that its *characteristic property* is proportional to the ratio of the area of the plates and the distance between the plates. He would then be told that this is called a *capacitor* and that the blue can in Fig. 1 is also an elemental capacitor but that its

ratio of area to separation distance of the plates is very large. It is used in the experiment by attaching one wire to one plate, and another wire to the other plate. Similarly, he would be shown the interior of the DC generator/motor and have it pointed out to him that it contains a permanent magnet, an assembly of coils of wire that rotate in unison and that pass near the magnet, and the commutator-and-brush assembly; but nothing in the generator/motor switches its *state* when the shaft is rotated in a clockwise or an anticlockwise direction. Thus, armed with this brief description of the equipment we can proceed with *his* analysis.

The approach is that contained in Aquinas' *Summa Theologica* and it relies on the following preconceptions: "In physics matter is studied only as mass in motion and its action and interaction upon itself. A further grade of abstraction is to the quantity of matter only, and therein we have the science of mathematics."

"Metaphysics goes beyond both of these grades of abstraction and proceeds to abstract the very nature of reality itself, the essence or nature of things. Thus, metaphysics goes beyond the mere physical or quantitative aspects of reality; it penetrates to the very ultimate nature of reality as such and seeks to discover/uncover those principles and perfections that are common to all reality. It has for its object the essences of things and their ultimate analysis into being, as well as the formulation of the principles that are true of all beings as such. It is the parent study to all other philosophy." [4].

The metaphysical answer: The motor will turn in the same clockwise direction as it was forcibly turned and this may be shown in two ways.

*The First Way*: "The argument of received forms in diverse things":
When the motor is turned in a clockwise direction, it is moved from potentiality to a state of actuality by an actual form of clockwise rotation. This form is received into the capacitor from the motor, for an agent acts according to its form. But what is received is received according to the condition of the recipient and this condition in the capacitor is such that it does not rotate or move in any way to receive the rotational form, and we may call this form in the capacitor, a form of charged capacitor, for a thing is according to its form. Now, since the capacitor does not have a form of rotation in its own form essentially (for a capacitor does not have moving parts), the form of a charged capacitor, which is received back into the motor, must manifest itself in the motor in the same way as it did previously, as clockwise rotation. Thus, in like manner when a piece of steel possessing the form of heat is placed into a bucket of water, thereby heating the water, the hot water (containing now the form of heat in its own mode) will heat (or re-heat) a piece of steel such that the form of heat in the steel will exist as it did previously (as hot steel; according to the form of heat). But if what is received into a thing has that form pre-existing in the recipient as part of its own determinate nature, then the determinate nature of the recipient would hinder and obstruct the form it receives, as a ball falling downwards when striking the ground receives a form from the ground itself which is contrary to the downward movement of the ball, and the ball bounces upwards. And since a form of rotation is not itself essential to the form of a capacitor as a capacitor (for it does not move/rotate in any way to work and still works whether it is moved/rotated or not), the clockwise form of rotation received into the capacitor is not hindered or obstructed by the form of the capacitor, unlike for example a spring which moves

according to its own form when wound up by a device and thus renders its own springy form back to the device when the device unwinds in a contrary motion.

*The Second Way*: "A body of contraries cannot exist": The motor connected to the capacitor may be viewed as a composite body (or a body composed of various parts). Now if a motor when turned in a particular direction can charge a capacitor by its contact with the capacitor and in like manner we are told that a capacitor will simultaneously discharge itself by contact with the motor, then as we observe the body of motor and capacitor remains intact when the motor is turned in a clockwise direction (the capacitor does not come apart from the motor), we must conclude that there is a natural tendency for the motor to turn in the same direction when the capacitor is being simultaneously charged and discharged, for a body of contraries cannot exist. For in like manner a clockwise rotation of a cogwheel (which is produced by an anti-clockwise rotation in a touching, engaged tooth) must have all touching engaged teeth from other cogwheels rotating anti-clockwise also for the body of cogwheels to turn, otherwise the composite body of cogwheels will come apart by the sheering away of teeth from *contrary* rotating cogwheels.

**8. Comments on Aquinas' Argument**

In his *Summa Theologica*, Aquinas prefaces his answer to a question with a series of *objections*, which purport to prove the contrary argument to his position. He then gives an *On the contrary* position which is an argument from authority. [In the Middle Ages the argument from authority was considered the weakest form of argument. However the authority he quotes is usually, but not always, a quote from scripture, the author of which actually created the Universe, and so this authority would be so certain that one can literally accept it on *faith* over and above the argument based on reason]. He then states his position, argued from reason after the words 'I answer that' and *then* he *replies* to the abovementioned objections.

In like manner, allow us to provide some *objections* and *replies* to our metaphysical arguments dealing with the motor and the capacitor.

*Objection 1*: The First Way argues that a *form of clockwise rotation* being in the motor which is then given to the capacitor and thus given back to the motor *still in a clockwise direction* for such *is* the form in the first place. But we observe that when a soccer ball falls towards the ground it has a form of movement towards the centre of the earth, but when it strikes the ground the ground gives back a contrary form to the ball such that the ball actually bounces and now moves upwards. Thus the First Way must be in error since the capacitor can in a similar way give a form back to the motor that is anti-clockwise and not clockwise, notwithstanding that it may receive a form of clockwise rotation from the motor.

*Reply to Objection 1*: As a soccer ball falls towards the ground it does have a form of movement towards the centre of the earth. But the ground, which is itself *not* moving towards the centre of the earth, thus has an essential form which is contrary and repugnant to the form of the falling ball; for the ground as such does not fall towards the centre of the earth as the soccer ball does. It is thus the ground's *own* form which hinders and obstructs the form of the falling soccer ball which is given to the soccer ball and this is *not* the original form of the soccer ball itself given to the ground. Thus in like manner,

if ice was to be placed in contact with extremely hot steel, the form of heat in the steel hinders and obstructs the form of coolness it receives from the ice and renders its own composite form of heat (slightly cooled by the ice) to the ice causing it to melt. Hence it is that if the capacitor was already charged in a different manner (with a different polarity), and thus had a form which was contrary and repugnant to the *clockwise* form of rotation in the motor, the capacitor's own form could render to the motor an *anti-clockwise* form of rotation; but this would not be as a result of the original clockwise turning of the motor, but of a contrary form present in the capacitor itself.

*Objection 2*: We observe that when a device connected to a spring is turned in a clockwise direction, this form is given to the spring which it receives according to its own mode. And when the spring unwinds, it gives a form back to the device which is anti-clockwise and not the same as the original form of clockwise rotation in the device. In like manner, the first way must be in error.

*Reply to Objection 2*: A form of rotation is already present in the spring as part of its essential nature as a spring (which gives the spring springiness). This therefore hinders and obstructs the form of clockwise rotation it receives from the device and renders an anti-clockwise form of rotation to the device. But a capacitor does not possess a form of rotation or movement essentially (as part of its determinate nature) and therefore the reception and return of the clockwise form is not hindered and obstructed by the capacitor's own form.

*Objection 3*: The second way must be in error because a device could be constructed which operates as a torque switch such that when the hand releases the clockwise torque on the knurled knob of the motor, it could reverse the polarity of the capacitor causing the motor to rotate in a contrary motion.

*Reply to Objection 3*: As the torque switch begins to operate by reversing the polarity of the capacitor, it causes the motor and the capacitor to momentarily come apart from each other (via the switch), for as stated above, a body of contraries cannot exist.

**9. Quo Vadis?**

What we hoped to have illustrated is the precariousness of scientific and even metaphysical explanations. We surmise that the incorrect answer to *The Question* arises from an analogy with, say, winding up a spiral spring in a clock. Once the torque of winding is released the spring unwinds in the direction *opposite* to its winding. Or, the forced rotation of a paddle wheel used to pump water up a hill to a dam then reverses when the forced rotation is stopped and the water runs back down the hill past the paddle wheel.

Fundamentally, the behaviour of the apparatus described here is embodied in the notion of conservation of momentum that appeared with Newton in the 17th Century and which then also was encapsulated in Lenz's law.

In following a line or argument based on momentum, if the knurled knob had reversed its direction the instant that any torque on it was released, then what would have happened if the torque was gradually decreased until is approached zero? One might say that the rotation would jump back in the opposite direction, whereupon a minute additional torque in the original direction would send the rotation back the other way. However, by then the momentum of the rotor would have been such that a much larger

torque would have been required to bring about a change in direction of rotation of the motor. This situation is clearly untenable. In other words, the discontinuity in the system-response would imply infinite impulse (force × time) at the moment of the change in direction of the rotor.

Perhaps this argument alone would lead someone, after some contemplation, to the correct prediction of the response of the system (or is this recitation really only the Second Way expounded above, in another form?)

## 10. Conclusions

Finally, our aim has been to stimulate reflection on what constitutes an acceptable scientific argument, and to indicate the power of metaphysical arguments. After all metaphysical arguments include the basis of what everyday scientists call 'logical deduction'.


## Acknowledgements

We thank David Philp, a former PhD student of PWK in molecular biophysics, for numerous stimulating discussions on this and related topics.


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