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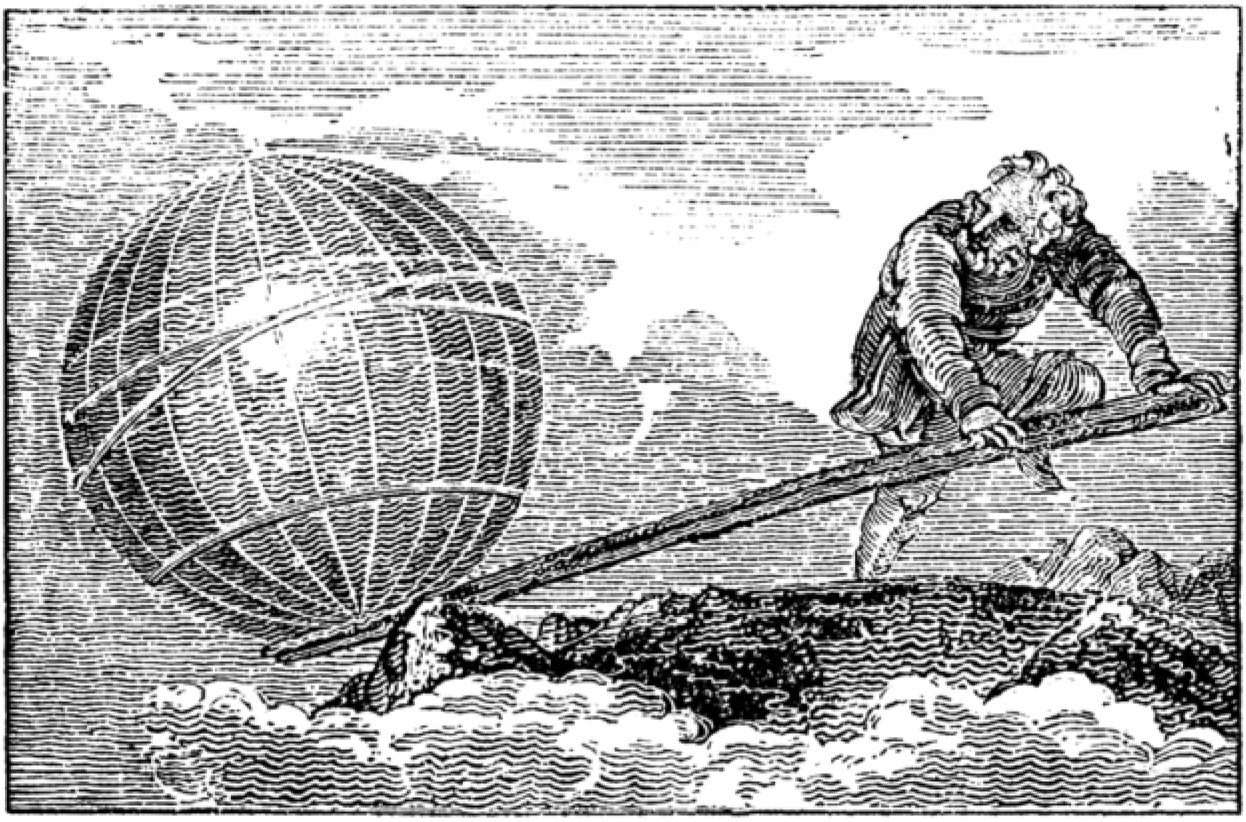
SECTION 1: Prologue–The Greek World

There are science-fiction stories, alternate history variety, in which science developed in Greek and Hellenistic civilizations. That it did not, is surprising. Certainly the great minds were there.

1.1 ARCHIMEDES



Archimedes Moving the Earth with a Lever
from Wikimedia Commons

Foremost among these great minds was Aristotle, a philosopher, and naturalist; the term “physics” comes from the title of his book “Lectures on Nature” (“Phusike Akroasis”) and although, as Bertrand Russell said about this work and also “On the Heavens”, “*there is hardly a sentence in either that is not contradicted by modern science*”, it set the stage for logical, rational study of the world around us. Where it fell short was relying not on empirical testing of propositions that seemed self-evident, for example: the heavier the body, the faster it would fall to the earth; an object needed a force to keep it moving or it would stop.

1.2 HELLENISTIC MATH AND SCIENCE

The Greek Hellenistic world also had its share of great minds. Eratosthenes calculated the size of the earth (accurate to within 200 miles) using trigonometry and sundials at different locations. Archimedes discovered the principle of buoyancy (whence “Eureka”) and set forth quantitative principles for the lever and the screw. He used approximation methods that foreshadowed the calculus to calculate the area and volumes of non-polygon shapes. Hero of Alexandria invented many ingenious engines and formulated a fundamental principle of optics, that light would take the shortest path within a medium. Examples of Hellenistic math and science are illustrated below. (To cycle through the images click on the first image and then click on the control arrow in the upper right hand corner to advance or stop.)

Hellenistic Math and Science

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Why didn’t science come forth from all these inventions and discoveries? Although many bore the marks of genius, they did not correspond to a unified scheme, a core of fundamental theory that is necessary for science. We'll see in the next section what was done in Medieval Christendom to give a unified scientific picture of the world.

SECTION 2: St. Augustine–A Theologian for Our Times

> *"Happy those who feast on wisdom and savor her knowledge, She will nourish and refresh them."*
> –Hymn for the Office of Readings, 28 August.

2.1 iNTRODUCTION

St. Augustine of Hippo lived in the last days of the Roman Empire. He died during the siege of his city by the Vandals. His Confessions should be (indeed are) required reading for all who want to understand what Catholicism is all about. I focus in this chapter on the strikingly modern positions he has taken on topics such as the literal truth of the Old Testament, creation, evolution, and the infinitude of God.

St. Augustine and the Fires of Wisdom, Philippe de DeChampaigne (1645)

2.2 SAINT AUGUSTINE: CREATION

St. Augustine held that God created the universe from nothing. Two fundamental (and surprisingly modern) notions were introduced by Augustine: based on Sirach 18:

1. Creation was instantaneous (6 days were a metaphorical device).
2. Not all animal forms were present initially at creation—for some, the potential or seed to develop later in a different form was given initially.

from Wikimedia Commons

St. Augustine argued that time began with the creation. He also stressed that one should not use Scripture to contradict what reason and experience ("Science") tells us about the world:

> *"Often a non-Christian knows something about the earth, the heavens, and the other parts of the world, about the motions and orbits of the stars and even their sizes and distances...and this knowledge he holds with certainty from reason and experience. It is thus offensive and disgraceful for an unbeliever to hear a Christian talk nonsense about such things, claiming that what he is saying is based in Scripture. We should do all that we can to avoid such an embarrassing situation, lest the unbeliever see only ignorance in the Christian and laugh to scorn."*
> –*De Genesi ad litteram*; the Literal Meaning of Genesis, an unfinished work.

2.3 SAINT AUGUSTINE: GOD AND INFINITY

Besides being ahead of his time in his ideas about creation, St. Augustine had profound and advanced ideas about the nature of God and infinity. Adam Drozdek (Associate Professor of Computer Science at Duquesne University) has written a fine article about this, Beyond Infinity: Augustine and Cantor, which I'll try to summarize below:

> *"There are three important aspects of Augustine's discussion of the problem of infinity. First, infinity is an inborn concept which enables any knowledge. Second, infinity can*

> *be found in the purest form in mathematics, and thus mathematics is the best tool of acquiring knowledge about God. Third****, God is neither finite nor infinite and his greatness surpasses even the infinite****.* [emphasis added] *Augustine is original in combining these three aspects in his philosophy; some of them can be found in other philosophers and theologians, but also in mathematicians."*
> –Adam Drozdek, "Beyond Infinity: Augustine and Cantor"

Augustine anticipates later developments in mathematics, the mathematics of infinity put forth in set theory, orders of infinity as proposed by the nineteenth Century mathematician George Cantor.

> *"All infinity is in some ineffable way made finite to God,"*
> –St. Augustine, "*De Civ. Dei* (The City of God)"

That is to say, God can understand all orders of infinity from aleph-0 to aleph-n; God is more, is greater than infinity.

SECTION 3: The Medieval Church, Midwife and Nursemaid to Science

3.1 SCIENCE WAS BORN: THE EDICTS OF PARIS, 1277

Some (perhaps many) atheists and materialists would say that science arose in the sixteenth and seventeenth centuries, fully mature, like Botticelli's Venus arising from the ocean. According to them it arose then because Europe had shaken off the limiting bonds of Catholic doctrine.

Pierre Duhem's historical studies of science show that this is not so. Rather, Duhem dates the birth of science as 1277, the year the Bishop of Paris, Etienne Tempier, condemned a number of errors from astrology and from the Peripatetic philosophers (those following

Aristotle). The condemned articles contended that the earth could not move, that worlds other than earth could not exist, that empty space (a vacuum) was impossible, and proposed principles of motion that were shown later to be false.

Bishop Tempier condemned the articles not because of scientific errors, but because they apparently limited God's power. Once these Peripatetic dicta were declared non-binding, scholars–almost all of them clerics–were able to explore new ways to explain the world around us, ways that would grow into the scientific method.

For cosmology—the science of the earth's place in the universe—to come about, the following errors had to be corrected:

- •That the earth could not move;
- •That the earth was at the center of the universe;
- •That different physical laws applied to the earth and to the planets;
- •Aristotle's theory of gravity.

According to Aristotle, gravity manifested itself in the following ways: heavy elements wanted to move to the center of the earth; the heavier the element (the more massive), the faster it would move; the lighter elements, air and fire, would move away from the center of the earth.

For dynamics—the science of motion—to move forward the following error had to be corrected:

> "[Aristotle*] held that the projectile was moved by the fluid medium, whether air or water, through which it passed and this, by virtue of the vibration brought about in the fluid at the moment of throwing, and spread through it [the vibration through the medium]."*

–Pierre Duhem, "History of Physics before Einstein"

When Aristotle's ideas were no longer regarded as the Ten Commandments of science, cosmology and dynamics could then develop into science as we know it today.

The development of cosmology culminated in the Copernican Revolution, the idea that the earth was no longer the center of the universe but revolved around the sun.   But there was much work preliminary to that–the notion did not spring full-blown to Copernicus. To explore this history in depth, please read Duhem's "History of Physics before Einstein" (linked above).

3.2 THE INFANCY OF SCIENCE: SOME MEDIEVAL SCIENTISTS

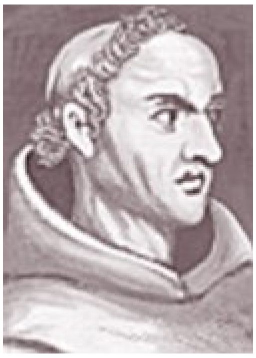
Even though Pierre Duhem regards the Edicts of Paris as marking the birth of science, there were important contributions before that time. Listed below are a few of those who started up the engine of science—you'll note that several of them lived before 1277 and that they were all clerics. A more complete history of the advances in mathematics, astronomy and physics achieved during the Medieval Ages is given in Pierre Duhem's masterwork linked above.


Robert Grosstete

- **•Robert Grosseteste, Bishop of Lincoln** • (1175-1253) introduced a principle fundamental to the practice of science: from particular observations a general law can be derived; then this law can be tested by additional observations of particulars—"resolution and composition",

•**Albertus Magnus (Albert the Great)**, (1200-1280) is the patron saint of scientists. He was the teacher of St. Thomas Aquinas, and made important contributions in zoology, mineralogy in addition to his important work in theology and philosophy.

St. Albert the Great



William of Ockham

•**William of Ockham** (1285-1350) introduced one of the prime principles of science, “Ockham’s Razor”. This states that one does not multiply hypotheses needlessly to explain a phenomenon. In other words, the simplest explanation that fully explains is the best.

•**Jean Buridan** (1300-1358) is probably more renowned for his analogy, “Buridan’s Ass”, than for his seminal contributions to the physics of motion: the idea of impetus (what we now call “momentum”) and inertia. Contrary to Aristotle, he maintained that a body would continue moving unless slowed down by friction, such as air resistance. He argued that a thrown body was set into motion by the arm of the thrower, and that the “impetus” of the moving body depended on how heavy it was (its mass) and its speed of motion. These were ideas taken up later by Galileo and Newton.

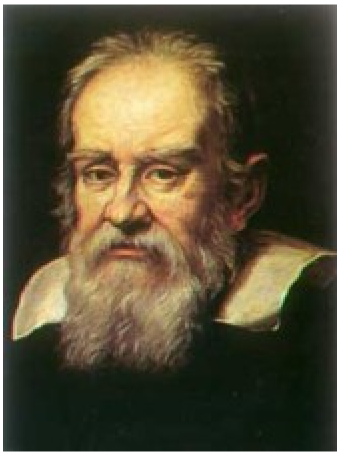
Jean Baptiste Buridan

Nicolas Oresme

•**Nicolas Oresme** (1322-1382) was eminent (as were most Medieval Scholastics) in many fields—astronomy, mathematics, physics, philosophy and theology. He anticipated Galileo by almost a hundred years in proving the mean speed theorem geometrically: the distance covered under uniform acceleration is given by multiplying the average speed by the time.

3.3 GALILEO: SCIENCE ENTERS ADOLESCENCE

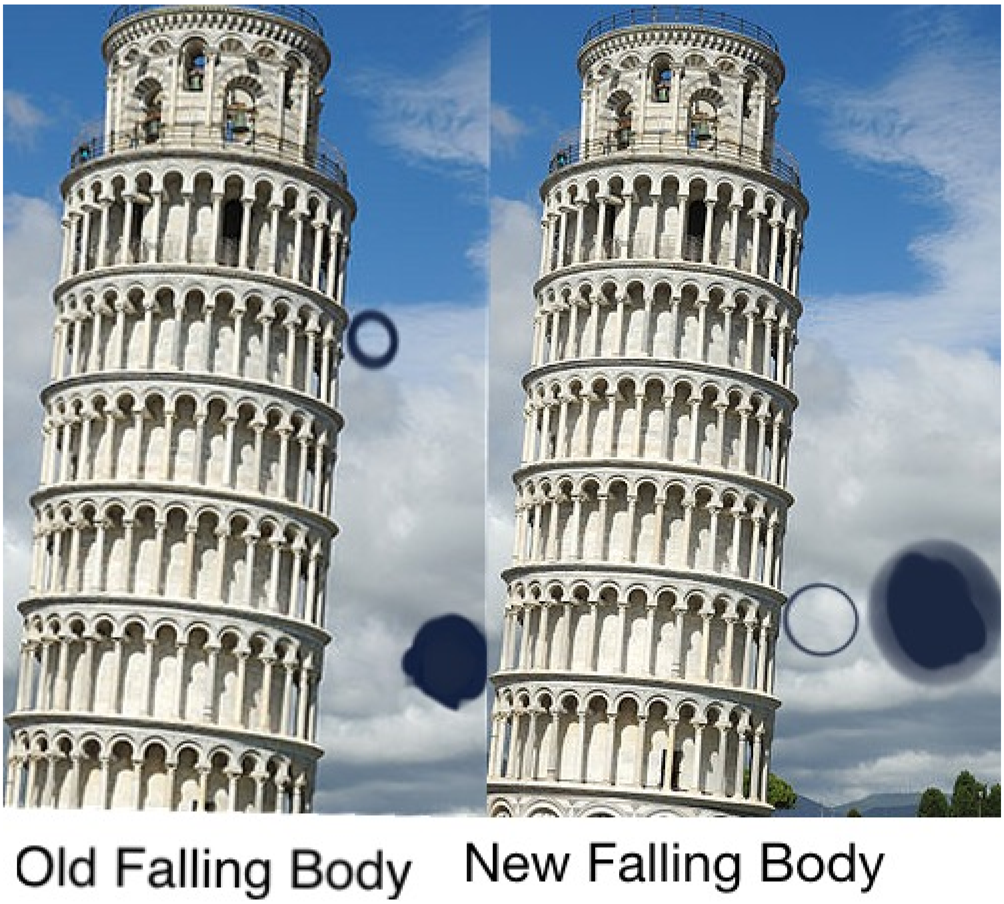
The work in physics and cosmology set the stage for Galileo–his important contribution was to introduce experimental tests of mathematical hypotheses. He used inclined plane experiments (I did these in my first year physics lab at Caltech) to formulate mathematical laws of motion about velocity and acceleration; he confirmed the Copernican hypothesis, that the earth revolved around the sun, by telescopic observations (see below). Thus, In the physics of motion–dynamics–he refined the idea of uniform acceleration. It should be noted that Galileo's ideas about dynamics did not yet reach the stage taught today in first year physics classes,



Galileo Portrait

"He then taught that the motion of a freely falling body was uniformly accelerated; in favour of this law, he contented himself with appealing to its simplicity without considering the continual increase of impetus under the influence of gravity. Gravity creates, in equal periods, a new and uniform impetus which, added to that already acquired, causes the total impetus to increase in arithmetical progression according to the time occupied in the fall; hence the velocity of the falling body."
–Pierre Duhem, History of Physics before Einstein

The picture below illustrates the well-known anecdote: Galileo tested his ideas about gravity and acceleration by dropping a light body (hollow circle) and a heavy body (filled in circle) from the Leaning Tower of Pisa. This was a "thought experiment" of his, not carried out, So we see that although Galileo achieved much in setting physics as a science, he still followed in the tradition of his predecessors.   The relation of acceleration to force had to wait for Newton's Law, Force= mass x acceleration or F = ma.



Galileo's Thought Experiment: Heavy and Light Balls fall at the same rate
Adapted from Wikimedia Commons.

Although Galileo made a huge step forward by his use of the telescope contributions to astronomy, he did build on the work of his predecessors. . He argued that the light and shadow patterns on the moon showed that it had mountains. He demonstrated the the planet Jupiter had satellites, and from the differing phases of Venus as it circled the sun, that the sun was the center of the solar system, and the earth orbited the sun. He also demonstrated that the sun had spots that moved with the rotation of the sun.

One point we should emphasize: despite his trials with Church hierarchy (see Section 4), Galileo was a true believer in God as author of a divine order that we could understand through science and mathematics:

> *"The laws of nature are written by the hand of God in the language of mathematics."* – Galileo Galilei (*Il Saggiatore*, 1623)

3.4 THE CATHOLIC CHURCH: NURSEMAID TO SCIENCE

Why did this development of physics and cosmology occur begin and grow in Medieval Christendom, but not in the ancient Hellenistic worlds or other civilizations? Excellent answers have been given in some detail by Fr. Stanley Jaki and Dr. Stacy Trasancos, but I want to add my own opinion.

•First, there was a world view, founded on Judaeo-Christian theology, that God was good and created a universe that was good and meant to be intelligible to mankind.
•Second, as Pierre Duhem pointed out, the Medieval scholars were freed in 1277 from erroneous restrictions they would have had to follow if Aristotle's principles were to be a compulsory base for theories.
•Third, in the earliest part of this growth they were priests; this meant that they had time to do scholarly work (as do academics today) and did not have to worry about earning a living from non-scholarly pursuits.

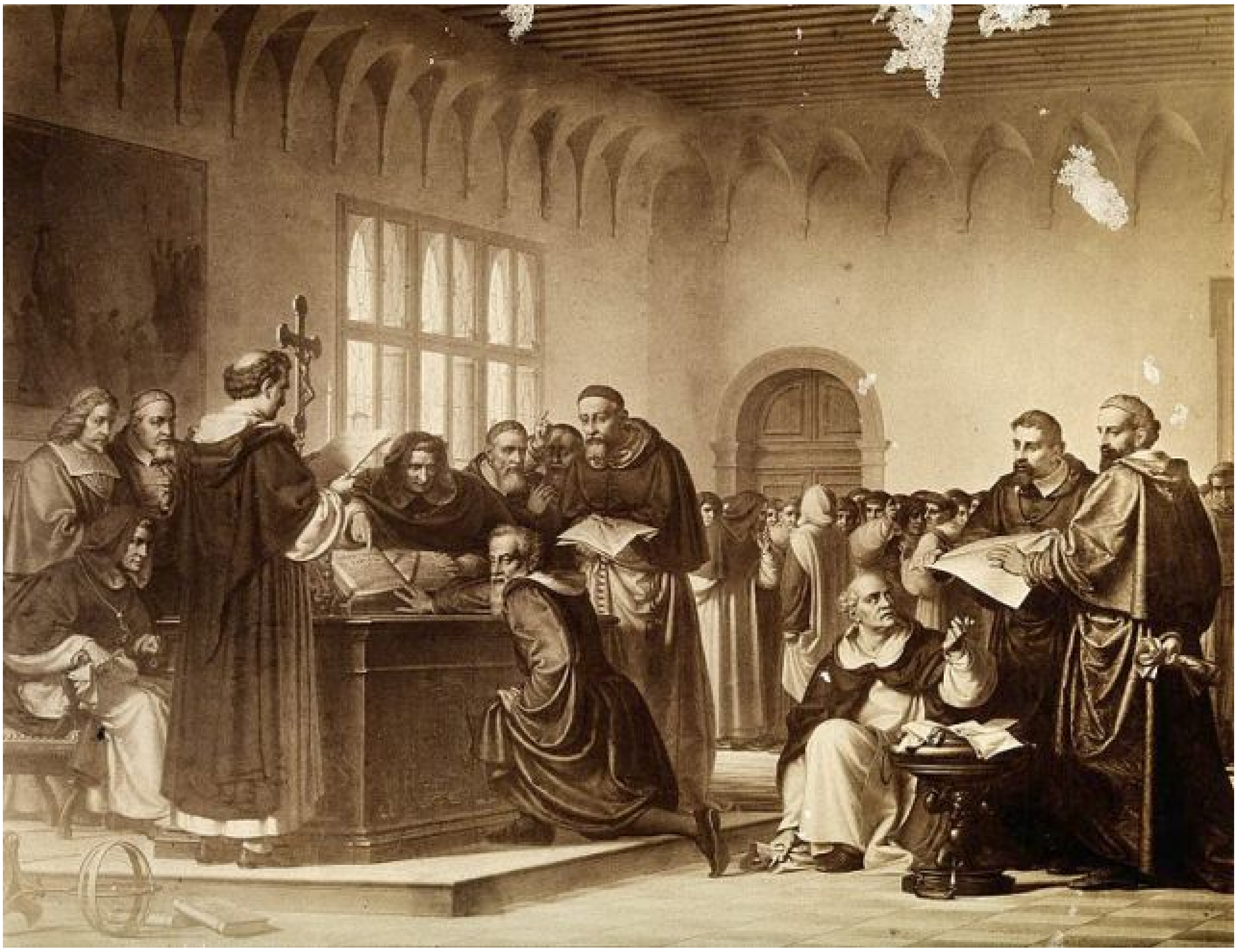
- Fourth, perhaps underlaying all the above, those in the Church were highly motivated to learn—to relate the world around them to that which Revelation and Faith had given them to believe. The term “scholastic” for these Medieval priests was apt indeed.

Finally, I want to emphasize again: there was a continuity of development from the 13th century to Galileo. Although his pioneering development of the experimental method to confirm mathematically expressed theoretical ideas laid the foundations for modern science, science did not spring fully new from Galileo’s work. He built on the work of his predecessors.

SECTION 4: Science “versus” the Church?

> *“Extinguished theologians lie about the cradle of every science as the strangled snakes beside that of Hercules; and history records that whenever science and orthodoxy have been fairly opposed, the latter has been forced to retire from the lists, bleeding and crushed if not annihilated; scotched, if not slain.”*
> — Thomas Henry Huxley, “Lay Sermons, Addresses, and Reviews”

4.1 DID THE CHURCH PERSECUTE GALILEO AND BRUNO?



Trial of Galileo (Wellcome file)
from Wikimedia Commons

As the quote above suggests, atheists have used the Catholic Church as a whipping-boy, have cast it as opposed to science and a persecutor of those who propose novel scientific ideas that disagree with its dogma. The two cases cited most frequently by these atheists are Galileo and Giordano Bruno.   As George Sim Johnston puts it:

"The Galileo affair is the one stock argument used to show that science and Catholic

dogma are antagonistic. While Galileo's eventual condemnation was certainly unjust, a close look at the facts puts to rout almost every aspect of the reigning Galileo legend."
–George Sim Johnston, "The Galileo Affair"

Summarizing his arguments, one can say that both Galileo and some Church officials were at fault, but it was a different time with different concerns–high officials in the Church, initially sympathetic to Galileo, were defending orthodoxy against the onslaught of the Reformation.

Galileo was condemned not for his advocacy of the Copernican theory per se, but for his advocacy that Scripture was to be interpreted loosely (even though the same had been done by St. Augustine). And his science was wrong–circular orbits for the planets and his theory of tides. All this is dealt with at greater length in the article linked above. Nevertheless, this one piece of history has been the cannon used in the war of materialists against the Church to support their perceived conflict between the Church and Science.

In 1979 Pope St. John Paul II asked the Pontifical Academy of Sciences to make an in-depth study of the affair. Commenting on their report in 1992, he said, as an apology, explaining what had happened:

"Thanks to his intuition as a brilliant physicist and by relying on different arguments, Galileo, who practically invented the experimental method, understood why only the sun could function as the centre of the world, as it was then known, that is to say, as a planetary system. The error of the theologians of the time, when they maintained the centrality of the Earth, was to think that our understanding of the physical world's structure was, in some way, imposed by the literal sense of Sacred Scripture…."
–Pope St. John Paul II, "Address to Pontifical Academy of Sciences", as quoted in L'Osservatore Romano N. 44 (1264) – November 4, 1992

Liberal news media made much of this apology, but it was only recognizing in a formal way earlier actions of the Church: removing Galileo's book from the index, setting up a Vatican Observatory. Pope St. John Paul II was setting the affair in a historical context. What was critically important in his apology was his affirmation that science and the Church both have domains of truth, domains which do not contradict each other–as in his address on evolution, "Truth cannot contradict Truth."

The trial of Giordano Bruno (1548-1600) has been used as another example that the Church is opposed to science. Bruno proposed a cosmology that was surprisingly modern: an infinite universe, stars very far away and a non-geocentric cosmology. However, the cosmology was founded on a mystical basis, not on science. In 1600 Bruno was burned at the stake for heresy. As argued in the Catholic Encyclopedia on Bruno, his proposed cosmology did not enter into the charges:

> "*Bruno was not condemned for his defence [sic] of the Copernican system of astronomy, nor for his doctrine of the plurality of inhabited worlds, but for his theological errors, among which were the following: that Christ was not God but merely an unusually skillful magician, that the Holy Ghost is the soul of the world, that the Devil will be saved, etc.*"
> ––Giordano Bruno, The Catholic Encyclopedia

Some historians do argue that Bruno's cosmological teachings played a part in his conviction for heresy. A good discussion of both sides of this controversy is given in the Wikipedia article on Bruno.

4.2 VITALISM AND DARWIN

That there is (or has been) a cold war between science and the Church should be surprising, if we acknowledge that that science grew in the soil of Medieval Christendom. In the sixteenth and seventeenth centuries those great men who laid the foundations of science—Galileo, Newton, Pascal—believed that the order of the universe was prescribed by God. Nevertheless, by the nineteenth century, as the domain of science spread to that which had been considered wrought only by the Divine—life and the chemistry of life—it seemed to many that there was no need for a God to make and sustain creation.

In the early nineteenth century the theory of "Vitalism" held sway. According to this theory there was a fundamental difference between organic compounds—compounds from biological sources—and inorganic compounds: living things were governed by different principles than inanimate matter and were endowed with a life (vital) force extending to their substance. The synthesis of urea and oxalic acid by Wohler in the early nineteenth century and the later conversion of carbon disulfide to acetic acid by Kobe convinced most scientists that chemistry was chemistry, with one set of principles for both organic and inorganic compounds.

The quote given at the beginning of this section was from an early champion of Darwin's theory of evolution, the biologist Thomas Huxley, known as "Darwin's Bulldog," He had many debates with clerics, the most notable of which was with Samuel Wilberforce, Bishop of Oxford, an account of which is given in the linked material. More is said about the Church's position on evolution below, but very briefly it can be said that the Church does not deny evolution as a scientific explanation for the diversity of species, but it does emphasize that there are different models for how evolution occurs, not only that of Darwin's "Survival of the Fittest."

4.3 POPE ST. JOHN PAUL II'S RAPPROCHEMENT WITH SCIENCE

> *"Science can purify religion from error and superstition; religion can purify science from idolatry and false absolutes. Each can draw the other into a wider world, a world in which both can flourish."*

–Pope St. John Paul II, Letter to Rev. George Coyne,S.J., Director of the Vatican Observatory.

Among the many posts and articles on the canonization of Pope St. John Paul II, there were only a few comments about his efforts to effect a rapprochement between the Church and science. The term "rapprochement" has been chosen with care: "*an establishment or resumption of harmonious relations*" (Oxford English Dictionary). The term is applied to peace treaties after a state of war, and although the Catholic Church has not declared war on science, there are those scientists who do think there is such a war, and there are those advocates of scientism–that science explains all we need to know about the world–who have declared war on the Church.

There are three ways in which Pope St. John Paul II tried to bring about this rapprochement:

Clearing up the Galileo affair;
Making the position of the Church clear, consistent with both dogma and science;
Setting up conferences on how Divine Intervention might be manifested in ways consistent with scientific theories.

The first has been discussed above; the second is discussed in Essay n; the third is discussed below.

In 1987 Pope St. John Paul II instituted the first of a series of conferences, held at the Papal Summer Residence, Castel-gandalfo, bringing together scientists, philosophers and theologians. Not all of these were Catholic and, indeed, a few were not even theists, as the term is commonly understood.

He addressed the conferees at this first meeting ("Our Knowledge of God and Nature: Physics, Philosophy and Theology") in a letter to George Coyne, SJ, Director of the Vatican Observatory. (The reader should go to the link above for that letter, to get the full import of his thoughts on science and the Church.) He stressed first, as in the quote at the beginning of this post, the contributions science could make to the Church and the Church to sciences. His comments show a sophisticated knowledge of frontier research in physics and biology:

> *"The unity we perceive in creation on the basis of our faith in Jesus Christ as Lord of the universe…seems to be reflected and even reinforced in what contemporary science is revealing to us….Contemporary physics forms a striking example. The quest for unification of all four fundamental physical forces–gravitation, electromagnetism, the strong and weak nuclear interactions–has met with increasing success….In the life sciences, too, something similar has happened. Molecular biologists have probed the structure of living material…(and) have discovered that the same underlying constituents (genes and proteins coded by genes) serve in the make-up of all living organisms on earth."*
> —Pope St. John Paul II, Letter to Rev. George Coyne, Director of Vatican Observatory

.Although he argued that science and theology could, and should, mutually enrich the other, he did not think they should be united as one discipline:

> *"By encouraging openness between the Church and the scientific communities, we are not envisioning a disciplinary unity between theology and science like that which exists within a given scientific field or within theology proper….The Church does not propose that science should become religion or religion science…To be more specific, both religion and science must preserve their autonomy and their distinctiveness….Christianity possesses the source of its justification within itself and does not expect science to constitute its primary apologetic [emphasis added]. Science must bear witness to its own worth….neither ought to assume that it forms a necessary premise for the other."*

> *—ibid.*

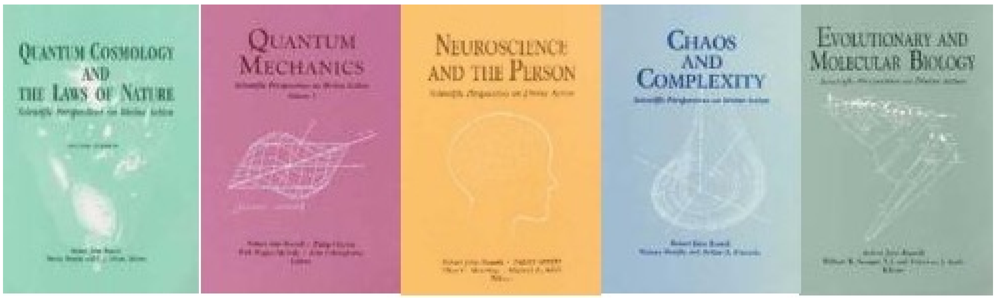
The quotation above reminds me of harmony parts: the musical lines are distinct, for the most part different, but the harmony enriches the melody, as does science, theology. Although Pope St. John Paul II respected the integrity and distinctiveness of science and theology, he did emphasize that they could and should enrich each other in areas such as cosmology and molecular biology, and, accordingly, set up conferences to show this enrichment. He stressed the importance of putting scientific findings in a proper context, and the difficulty of doing such in our contemporary setting:

> *"For the truth of the matter is that the Church and the scientific community will inevitably interact….Christians will inevitably assimilate the prevailing ideas about the world, and these are inevitably shaped by science. The only question is whether they will do this critically or unreflectively, with depth and nuance or with a shallowness that debases the Gospel and leaves us ashamed before history. Scientists, like all human beings, will make decisions on what gives value and meaning to their lives and to their work.* ***This they will do well or poorly, with the reflective depth that theological wisdom can help them attain, or with an unconsidered absolutizing of their results beyond their reasonable and proper limits."***
> [emphasis added]
> —ibid.

The last sentence in the above quote applies very well to those scientists who would deny God because they believe that only science truly explains the world (and us).

Finally, here is a list of these conferences and links to the proceedings published by the Vatican Observatory and University of Notre Dame Press. On the web page of the Center for

Natural Sciences and Theology that lists the books, you will see images of each book. If you click on the book image at that web site, there will appear article headings at the right of the web-page, which will link to the article of interest.



Cover Images for Conferences on Scientific Aspects of Divine Intervention

SECTION 5: Science Background–Elements of the Physics of Motion

5.1 INTRODUCTION

This section is for those students who don't remember (or perhaps never were taught) elementary physics. I hope to give some qualitative notions of some basic concepts in physics and to do so with a minimum of mathematics, using pictures, animations and links to available explanations on the web.   So, dear reader, imagine you're living in pre-Renaissance Europe, and are listening to those Medieval monks explain what they think about motion, and how it differs from what Aristotle had to say.

5.2 DISTANCE, VELOCITY, ACCELERATION

First, let's consider **distance**. I believe all you readers have an intuitive notion of what distance is: you draw a straight line between point A and point B and the length of that line is the distance between points A and B.[1]

What is **velocity**, then? Velocity is a rate, distance per time. (And, to be fussy, velocity has direction; “speed” is the magnitude of velocity; you don’t care what the direction is; velocity is “speed” plus direction.)

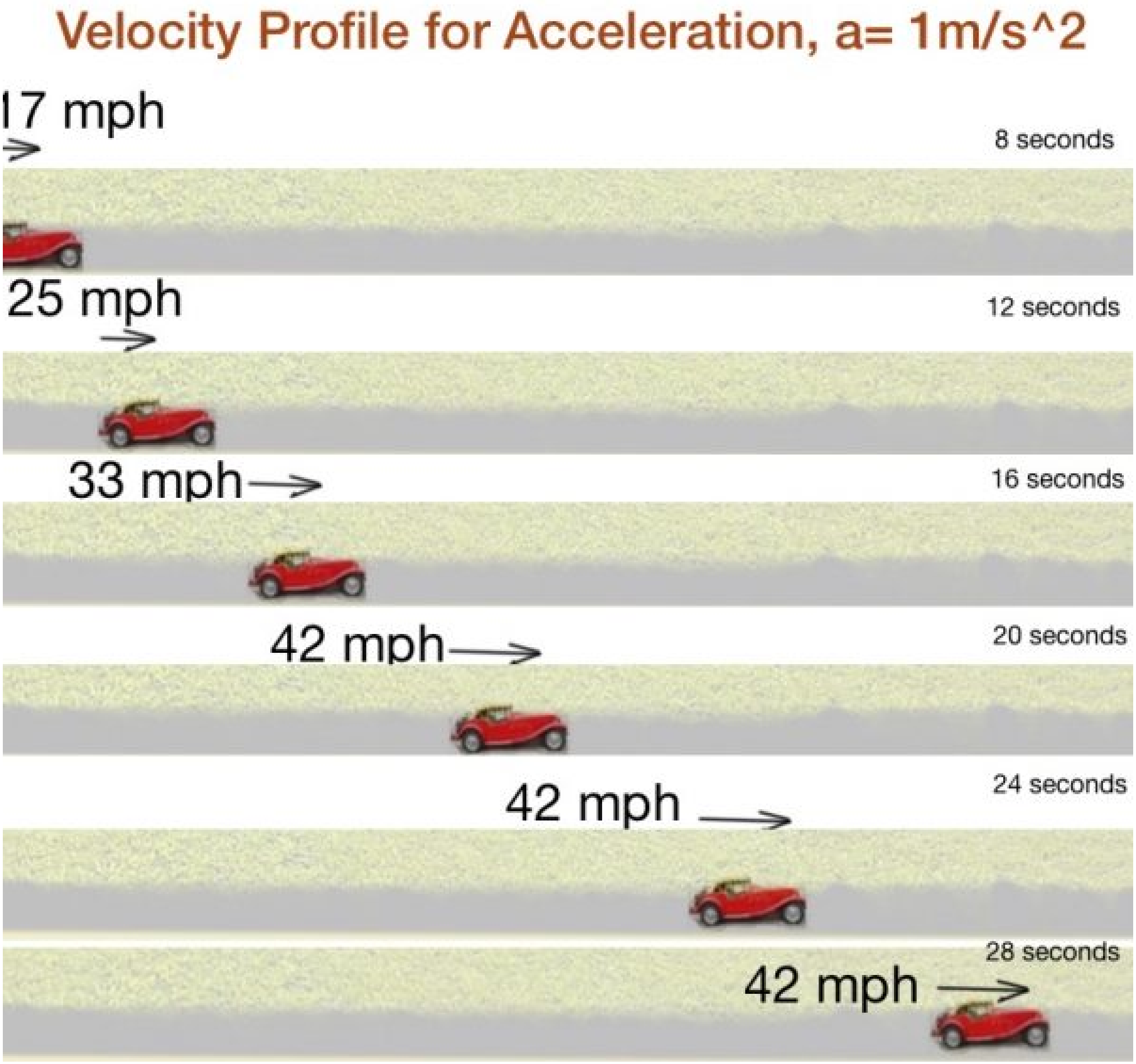
Now I ask your pardon, dear reader to bear with me while I inject just a little math to make the concept clear. Suppose it’s four miles to the nearest rest stop on the thruway and you must get there in five minutes (or less–I won’t ask why.   How fast do you have to travel or what should your car’s velocity be? Your rate of travel, speed, must be four miles in five minutes, or 4miles/ 5 minutes, or as it would be written conventionally, 4/5 miles/minute; in other words, distance divided by time.   Since there are 60 minutes in an hour, a little arithmetic shows you would have to travel 60x (4/5) miles/hour or 48 mph[2]. And here’s an equation (again, pardon)

$v= d/t$ where v is velocity, d is distance and t is time to travel that distance

What is **acceleration?** It’s also a rate, the change in velocity divided by the corresponding change in time. Let’s turn again to an example with some numbers. Fresh out of grad school I bought a MG TD (red, no less!).   The MG was not, to use my grandson’s lingo, “zippy.” From a standing start, it could get to a speed of 42 mph in about 20 seconds (real sports cars take only about 5 seconds to get to 60 mph).   This acceleration rate corresponds happily (for nice numbers) to about 1 (m/s)/s or 1 m/s^2.   So we have **acceleration, a**, given by the gain in velocity over the time, t, it takes to achieve that change:

a = change in v / t

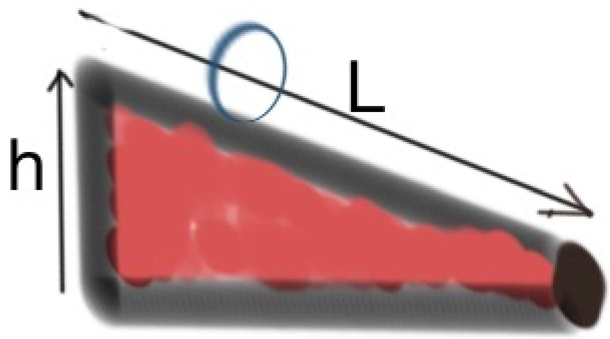
Here’s an illustration to give you some notion of what acceleration and velocity look like. It’s the MG TD performing as above, going from 0 to 42 mph in 20 s and thereafter at the constant speed of 42 mph. The shots correspond to 4 s intervals from 8s to 28 s.



Velocities at 4 second intervals from 8s to 28 s. Acceleration is 1 m/s^2, to get to 42 mph in 20 s. Acceleration ceases at 20 seconds, so velocity is constant from 20 seconds to 28 seconds; the speed is listed above each car image; the arrow length corresponds (roughly) to the velocity:

An easy way to think about constant acceleration is that the distance covered in a given time is average velocity multiplied by the time.   The average velocity is just (1/2) (v_beginning + v_end).[3]

As pointed out in SECTION 3.2, Nicolas Oresme had derived these relations between velocity, distance and acceleration by a graphical analysis, 100 years before Galileo.   However, it was Galileo who did the science: confirmed the theory by experiment.



Inclined Plane used by Galileo to measure relation between distance, velocity and acceleration

How did Galileo set up an experiment where the motion would be slow enough for him to measure time, distances and speed? Acceleration of falling bodies would be too fast.   Here's the experiment, done in elementary physics lab classes.   An inclined plane, as in the illustration below, length L, is set up so that the top end of the plane is a height h above the ground. A ball or cylinder rolls down the plane and you measure distance traveled in given times. Now if the plane were to be vertical (h=L), the ball would fall with an acceleration that of gravity (9.8 m/s^2) and that would be too fast. If the plane is flat (h=0), the ball would not roll at all (hey! that's poetry?). Clearly the acceleration is going to vary as the height h changes.   It turns out that the acceleration is proportional to h/L. It will be the same–independent of size or material–for a given shape sliding or rolling down the plane.

5.3 MOMENTUM

How do objects acquire velocity, that is accelerate? Buridan in the 14th Century had ideas about velocity that anticipated Galileo and Newton centuries later. He said that a moving body had "impetus," the heavier the body moving at a given velocity, the more impetus it had. If you threw a ball, the motion of your arm gave the ball its impetus. "Impetus" is what we now call "momentum" and define as

$$\text{momentum} = \text{mass x velocity}$$

Mass is what we ordinarily think of as weight, but to be fussy, weight is really mass times the force of gravity. You can think of mass as resistance to change in motion, what would technically be termed "inertia."

Here's an example to give you some intuitive notion about momentum: the MG TD referred to above is a very light car, weighing only about 1/2 ton (1000 pounds); a late model Cadillac is much heavier, weighing about two tons. Accordingly, the mass of the Caddy is about four times greater than that of the MG. So, if the MG were traveling at 40 mph and the Caddy at (1/4)x 40 mph = 10 mph, they would have equal momentum (if they were traveling in the same direction–remember, velocity has direction, speed does not). This is illustrated in the animation below.

[soliloquy id="810″]

5.4 FORCE

What causes a body to accelerate, acquire velocity? Again, Buridan had the right qualitative notion: the body acquired impetus because of an action by an agent, you, throwing the ball with your arm. In this notion there is an implied notion of force, which Newton (17th century) made explicit by his Second Law of Motion:

Force = mass x acceleration

more generally if mass doesn't stay constant (think of an example involving liquids!)

Force = change of momentum/change of time

For the first definition, go back to the example of the accelerating MG: the force is provided by friction between the tires and the road, the tires—wheels—are made to go round by the engine turning a drive-shaft.

For the second definition, think of a pitcher winding up and releasing a baseball moving at 90 mph as depicted in this video . The baseball has a mass of about 0.15 kg (or about 0.3 lbs) If you go frame by frame in the video, you'll see that it takes less than 10 ms (0.01 s) for the pitcher to start his windup and release the ball; that's the change in time for the baseball to acquire its velocity of 90 mph (we'll neglect air friction slowing the ball down). So, fussing with units—I don't need for you all to mess with the arithmetic—you get a force of about 650 Newtons required.

For comparison, the force of gravity on the baseball is about 1.5 Newtons. If air friction is neglected, from what height would the ball have to fall to get this 90 mph velocity? About 100 yards. Why the greater force to throw the ball this fast?   Because the force of the throw is acting for only a short period of time, during the pitcher's windup, whereas gravity will be acting all during the fall.

5.5 ENERGY AND WORK; CONSERVATION OF ENERGY

There are two other physics concepts, as important as velocity, acceleration and force, that bear on motion, and those are energy and work.   To get an intuitive idea of this, let's go into more detail about how the MG acquires velocity.

First, fuel is burnt in the cylinders to move the pistons up and down and thereby rotate the shaft that turns the rear wheels around, moving them against the friction of the road.   We have then chemical energy from the gasoline combining with oxygen (burning) converted to mechanical energy.   The energy of motion is called "**kinetic energy"** and is given by the formula

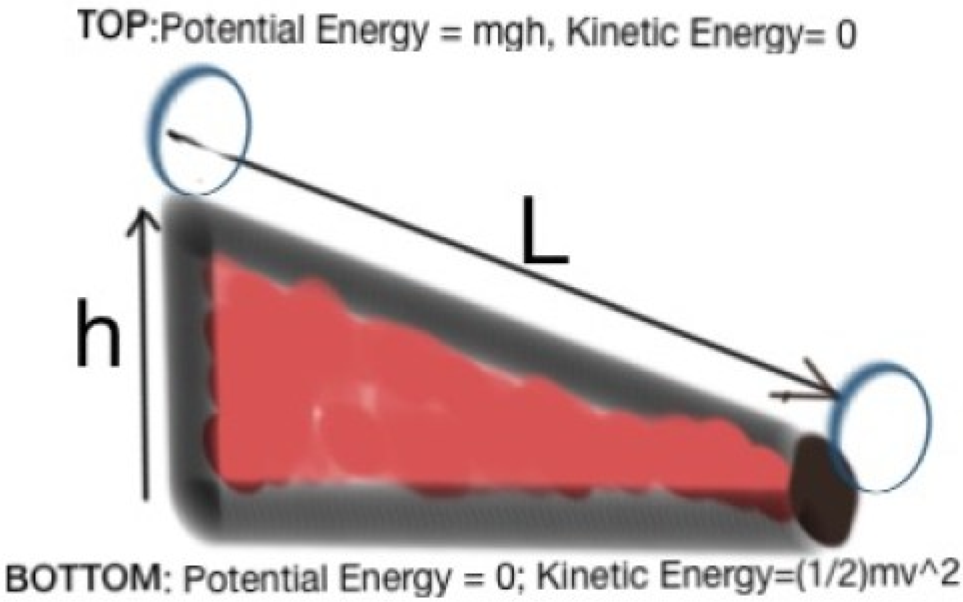
Kinetic Energy = (1/2) mass x velocity^2

Another important form of energy is "**potential energy,**" energy a body has by virtue of its position. Let's think about what this means. When you let a ball roll down an inclined plane it has zero kinetic energy at the top and kinetic energy at the bottom after it's accelerated due to gravity and acquired velocity.   So where does that kinetic energy come from?   To balance the energy books we say the ball at the top of the plane has potential energy that can be converted to kinetic energy.   This potential energy is given (for gravity at the surface of the earth) by

Potential Energy = mass x g x h= mgh

where g is the acceleration due to gravity (9.8 m/s^2), h is the height above the bottom

This is illustrated below:



Potential Energy Changed to Kinetic Energy as Ball Rolls down the Inclined Plane.

An important principle of physics is that **energy is conserved.** What does that mean? It means that energy doesn't disappear into nowhere, for example:

kinetic energy, energy of motion is lost due to friction, but is converted to the same amount of heat energy;
kinetic energy, energy of motion is lost due to work done, moving the MG up a hill–the work done is equal to the amount of kinetic energy lost; the work done is equal to the gain in potential energy at the end;
chemical energy of the gasoline is converted to kinetic energy less friction losses in the engine and drive shaft.

Accordingly, the energy bank account balances: input (at the beginning) of chemical energy, gasoline in the fuel tank = kinetic energy at the end of the drive, when the fuel tank is empty + energy lost due to friction of the tires with the road, engine and drive shaft friction + work done due to a net change in height level at the end or gain in potential energy.

In Essay 2, we'll have more to say about energy and the science of energy, "Thermodynamics," particularly those two important laws: **The First and Second Laws of Thermodynamics**.

5.6 NOTES

[1]Let me add a cautionary note physicswise: if you are traveling between A and B (home and the local fastfood place, let's say) and you wander around, make side-trips, the distance is still the length of the line between beginning and ending points. If you want to get total mileage traveled, then you have to draw straight lines between each of the intermediate starting and stopping points and add the lengths up.

[2] Since each hour contains 60 minutes, you would have to go 60 (~~minutes~~/hour) x (4/5) (miles/~~minute~~) or 60 x (4/5) (miles/hour)= 48 (miles/hour).

[3]For our example, the distance covered by the accelerating MG between 12 seconds (v_beginning = 25 mph) and 16 seconds (v_end=33mph) is just

(1/2) (25+33) (miles/~~hour~~) x(1 ~~hour~~/ (3600 ~~seconds~~) x (16-12) ~~seconds~~ or about 56 yards