Ideas of Modern Physics

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Foundations of Modern Physics

Ideas the play key roles in modern physics

– Gravity
  • Both obvious and enigmatic

– Mathematics as the language of science

– Newton’s laws; Newton’s world

– The observer
  • The fundamental concept of classical physics

– What is gravity
  • The concept of a “field”
Gravity
Issac Newton

He did report watching apples fall while walking through an orchard

More later.....
What is Gravity

• We are all familiar with gravity
  In fact we can’t get away from it!

• Gravity is what causes things to fall ‘down’
  – Conversely it also defines ‘up’

• At the same time gravity that holds our solar system, our galaxy and our cosmos together

  That’s where we will start
Motion of Planets

• In ancient times the sky was an integral part of daily life
  • It provided illumination and at night it provided orientation; it also provided a calendar

• Motion of stars and planets had been charted Babylonian astronomers

• Greek astronomers (Hipparchus) produced star charts a way to calculate celestial motion

• This provided the raw material
Ptolemy

• Ptolemy took the existing information and developed a ‘model’ to explain the motion
  – He was probably not the only one, but he wrote it down and the writing survived

• He was Greco-Roman living in Alexandria under the Roman Empire circa 98-168AD
  – His major work *Almagest* was preserved in Arabic

• Hipparchus star maps covered the world he could see … Ptolemy’s model described the sky he could see
Geocentric Model

- Celestial bodies rotate in circles around the earth (deferent)
- Earth is offset from centre of rotation
- Planets rotate in an epicycle around a point on the deferent
- Describes ‘retrograde motion’
Ptolemy Model
Geocentric Model

• Ptolemy’s model remained in use for almost 1500 years because
  – It described what was known
  – It allowed predictions
  – It was ‘common sense’

• Little progress was made in scientific thought through middle ages ... theology dominated
A Basic Idea of Science

• A scientific model or theory predicts what we confirm using the information available
• Every successful describes the physical world...

• ........ For Now!
The next thousand years

• Little or nothing happened in Europe
• Learning centred in Muslim, Mongol and Chinese empires
• Najm al-Din circa 1277 wrote a treatise on motion around the sun then abandoned it
  – Maragha Observatory, Persia est. 1259
• Following astronomers developed computational techniques
Copernicus

• Lived 1473-1543 in Polish part of Royal Prussia
• Studied in Krakow and the Bologna
• While in Italy he studied Greek texts relating to Aristotle’s theory of homocentric spheres as well as Ptolemy
• He lectured (privately) on ‘mathematical solutions to astronomical problems’
• He made an observation that didn’t quite agree with Ptolemy (1497)
• About 1502 he translated (from Greek to Latin) 7th century Byzantine poems
Copernicus

• His first description of a heliocentric model was 1514

• A full mathematical description was published in 1542, the year of his death
  – Although it had been known among his friends since 1533 but was reticent to publish it
  – He also published a treatise on trigonometry
The Copernicus Model

• Seven Postulates
  – There is no centre of all celestial circles or spheres
  – The centre of the Earth is not be center of the universe, but only of gravity and of the lunar sphere
  – All spheres revolve about the sun as their midpoint, therefore the sun is the center of the universe
  – The distance from the Earth to the sun is imperceptible compared to the height of the firmament
  – Whatever motion appears in the firmament arises from the Earth’s motion
  – Apparent motions of the sun are caused by motion of the Earth as it rotates around the sun like any other planet. The Earth has more than one motion
  – Apparent retrograde motion of planets arises from Earths motion alone
Controversy

• Initially there was only mild controversy
• Within several years the Catholic Church (Bartholomeo Spina and G. Tolosani) ~1445
• Used style of Thomas Aquinas based on philosophical arguments:
  – Assumed motion of the Earth but proposed no mechanism
  – Thought process was backwards:
    • Thought of an idea and sought data to support it
    • Making observations and deducing an idea
Philosophical Arguments

– Started with “inferior” fields of science to make pronouncements on “superior” fields
  • Mathematics and Astronomy are inferior
  • Physics and Cosmology are superior

• Based on Aquinas (and Aristotle) that:
  – Mathematical numbers are a mere product of the intellect without any physical reality
  – “numbers could not provide physical causes in the investigation of nature”
Religious Arguments

• Primary argument from the Battle of Gideon (Joshua) “causing the sun and moon to stand still”

• Three points of argument
  – Evidence of the senses
  – Thousand-year consensus of men of science
  – Authority of the Bible
Religious Arguments

• The arguments continued past 1616
• Which brings us to Galileo
Galileo

• Galileo Galilei 1564-1642
• Probably greatest accomplishment as an astronomer:
  – Designed and built the first good telescopes in Europe (~30x)
  – 4 moons of Jupiter (1610)
  – Rings of Saturn
  – Neptune
Galileo

- 4 phases of Venus (only predicted by heliocentric model)
- Sun Spots
  - Annual variation
- Kepler’s supernova
  - No diurnal parallax
  - Thus distant star
  - Suddenly appeared
  - Heavens not immutable

Geocentric Model
Galileo and the Church

• Galileo’s new observations provided strong evidence to support a heliocentric model
• It convinced many astronomers to move towards a hybrid model on the way to heliocentism
• Galileo’s approach to the biblical references (constancy) was to follow Augustin’s position:
  Not to take scripture too literally, particularly when it is a collection of poems and songs vs history and instruction
Galileo and the Church

- Galileo also (unintentionally) upset/insulted the Pope
- Was arrested by the inquisition (1633)
- Found "vehemently suspect of heresy"
- Subjected to imprisonment at the pleasure of the inquisition ... commuted to house arrest for life
- During imprisonment he wrote his major works on kinematics and strength of materials
Galileo and Gravity
Galileo and Gravity

• Galileo was able to link the force of gravity to the motion of objects mathematically
  – Modern math notation had not been developed so it is largely described in words (parabola)
• He described objects accelerating when a force was applied
• He described how objects would fall at the same rate (in a vacuum)
Centripetal Force
• Galileo was able to derive the relationship using:
  • Geometry
  • His concept of ‘forces causing motion’

\[ a^2 + b^2 = c^2 \]
In fact the ‘experiment’ was described by a student and may not have happened
Descartes

• René Descartes
  – Philosopher
    • Proofs for the existence of God
    • Meditations
    • “I think therefore I am”

  – Mathematician
Descartes

• Algebra

\[ a^2 + 2ab + b^2 = (a + b)^2 \]
\[ a^2 - 2ab + b^2 = (a - b)^2 \]
\[ a^2 - b^2 = (a + b)(a - b) \]
\[ a^3 + b^3 = (a + b)(a^2 - ab + b^2) \]
\[ a^3 - b^3 = (a - b)(a^2 + ab + b^2) \]

• Analytic Geometry
  – Linked algebra and classic geometry

\[ \frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1 \text{ (ellipsoid)} \]
\[ \frac{x^2}{a^2} + \frac{y^2}{b^2} - \frac{z^2}{c^2} = 1 \text{ (hyperboloid of one sheet)} \]
\[ \frac{x^2}{a^2} + \frac{y^2}{b^2} - \frac{z^2}{c^2} = -1 \text{ (hyperboloid of two sheets)} \]
\[ 2z = \frac{x^2}{a^2} + \frac{y^2}{b^2} \text{ (elliptic paraboloid)} \]
\[ 2z = \frac{x^2}{a^2} - \frac{y^2}{b^2} \text{ (hyperbolic paraboloid)} \]
Cartesian Coordinate System

(-3,1)  (0,0)  (2,3)

(-1.5,-2.5)
1500 Years

• We know that there is a force (gravity) acting on all objects on Earth
• It seems to be a constant force (doesn’t) depend on location
• There is also some sort of force that holds the planets in position around the sun.

• The question is how it works ......
Isacc Newton

He did report watching apples fall while walking through an orchard
Isacc Newton

• Born 1642 Lincolnshire, Died London 1727
• One of the most pivotal scientists of all time
• He was foremost a mathematician
• He developed mathematical techniques to describe real world phenomena
• Fully demonstrated the value of mathematical physics
Contributions

- Laws of motion
  \[(x + y)^r = \sum_{k=0}^{\infty} \binom{r}{k} x^k y^{r-k}\] (2)

- Binomial Theorem

- Calculus

  \[f'(x_0) = \lim_{h \to 0} \frac{f(x_0 + h) - f(x_0)}{h} = \lim_{h \to 0} \frac{(x_0 + h)^{1/2} - (x_0)^{1/2}}{h}\]

  \[= \lim_{h \to 0} \frac{[(x_0 + h)^{1/2} - (x_0)^{1/2}] [(x_0 + h)^{1/2} + (x_0)^{1/2}]}{h[(x_0 + h)^{1/2} + (x_0)^{1/2}]}\]

  \[= \lim_{h \to 0} \frac{(x_0 + h) - x_0}{h[(x_0 + h)^{1/2} + (x_0)^{1/2}]} = \lim_{h \to 0} \frac{h}{h[(x_0 + h)^{1/2} + (x_0)^{1/2}]}\]

  \[= \lim_{h \to 0} \frac{1}{[(x_0 + h)^{1/2} + (x_0)^{1/2}]} = \frac{1}{x_0^{1/2} + x_0^{1/2}} = \frac{1}{2x_0^{1/2}} = \frac{1}{2} x_0^{-1/2}\]
Gravitation

• Using his mathematical formulation he was able to show that the elliptical planetary orbits described by Kepler required a centripetal force

• That the force was proportional to the square of the distance
  – This required accurate orbit information collected by Kepler and Tyco Brahe
Gravitation

Orbit of a planet is elliptical and dependent on the square of the distance \( \frac{1}{r^2} \)

Newton could apply the same mathematics to determine orbits of comets
Gravitation

• Gravitational force also depends upon the mass of the two objects
  – *Gravitas* ... Latin for weight

• *The greater the mass the larger the attractive force*

• *The greater the separation the weaker the force*
• Which takes up back to the apple tree ....

What Newton was thinking
Thoughts...

• Why do all apples fall in the same direction?
  – Universal law of gravitation

• Why is that direction perpendicular to the surface of the Earth
  – Concept of centre of mass

• What makes it happen
  – Concept of a gravitational field
How does the force ‘work’

• A very good question ....
  – We know it does

Physical Explanation

• Perhaps there is a physical ‘ether’ between all objects that allows objects to exert a force on each other

• Even our atmosphere cannot exert a tensile (pulling) force
Newton’s Impact

• One could now predict the behaviour of physical objects
  – Artillery, steam, time keeping
• One could predict astronomical phenomena
• There was a feeling that, given enough information you could calculate and predict human behaviour
• The tools he developed led directly to the industrial revolution
Newton’s Impact

• Newton was highly regarded in his time
  – Voltaire attended his funeral
  – Pope wrote a eulogy
  – Buried in Westminster Abbey

• He described a world where everything was fixed: position, forces and actions all could be described
  – This was contrary to Descartes who explained a world base on relationships between things
Mathematics to Explain Things

• Newton was able to formulate these ideas
  – Combine them into a mathematical formula

\[ F_g = \frac{G M_e m_m}{r^2} \]

Where G is “the gravitational constant”
Mathematics to Explain Things

• Universal Law of Gravitation
  – Describes what happens
  – Can predict what will happen
    • If the conditions remain the same
    • What are those conditions

\[ F_1 = F_2 = G \frac{m_1 \times m_2}{r^2} \]
Newton’s Impact

• The importance of Newton’s contribution is that he was able to solve the problem of how objects behaved on the human scale:
  – The objects we encounter every day
  – The objects we can see in the sky
• It remained the complete description until technology allowed us to see smaller or larger objects
How does the force ‘work’

Mathematical Physics Concept

Gravitational Field

Around the Earth there is a ‘field’ which is defined only by the force of attraction on an object at that point.
The Mathematical Language

• Mathematical language allows concepts to be concisely described.
  – Allows predictions to be made which can be tested
  – Allows manipulation of mathematical/physical concepts e.g. solving an equation
  – Allows manipulation of complex ideas
The Mathematical Language

The mathematical physics process:

1. Interpret a physical situation in terms of a mathematical system
2. Solve the mathematical system
3. Use the mathematical system to make predictions
4. Conduct the physical experiment to verify that the expected result is obtained (or not)
Scientific Method

1. Research
2. Make a Hypothesis
3. Collect Data
4. Observe & Experiment
5. Compile Data
6. Form Conclusions
7. Evaluate & Apply Results
8. Collect even more data
9. Refine a “Problem”

Scientific Method
Classical ‘Newtonian’ Physics

- Physical actions can be described mathematically and verified experimentally
- Physical actions are reversible
Classical ‘Newtonian’ Physics

- The same thing will be observed regardless of where you are standing
Newton’s World

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Newton’s World

• Newton’s description of the world and underlying ‘Natural Philosophy’ is extremely effective in:
  – Predicting outcomes of our everyday life
  – Explaining the world we perceive

• This is perhaps the a priori world as developed by Aristotle, Pythagoras and Galileo
Newton’s World is Our World
Newton’s Impact

• In fact it was Newtonian mechanics that got us to the Moon
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