4 20th-CENTURY SCIENCE

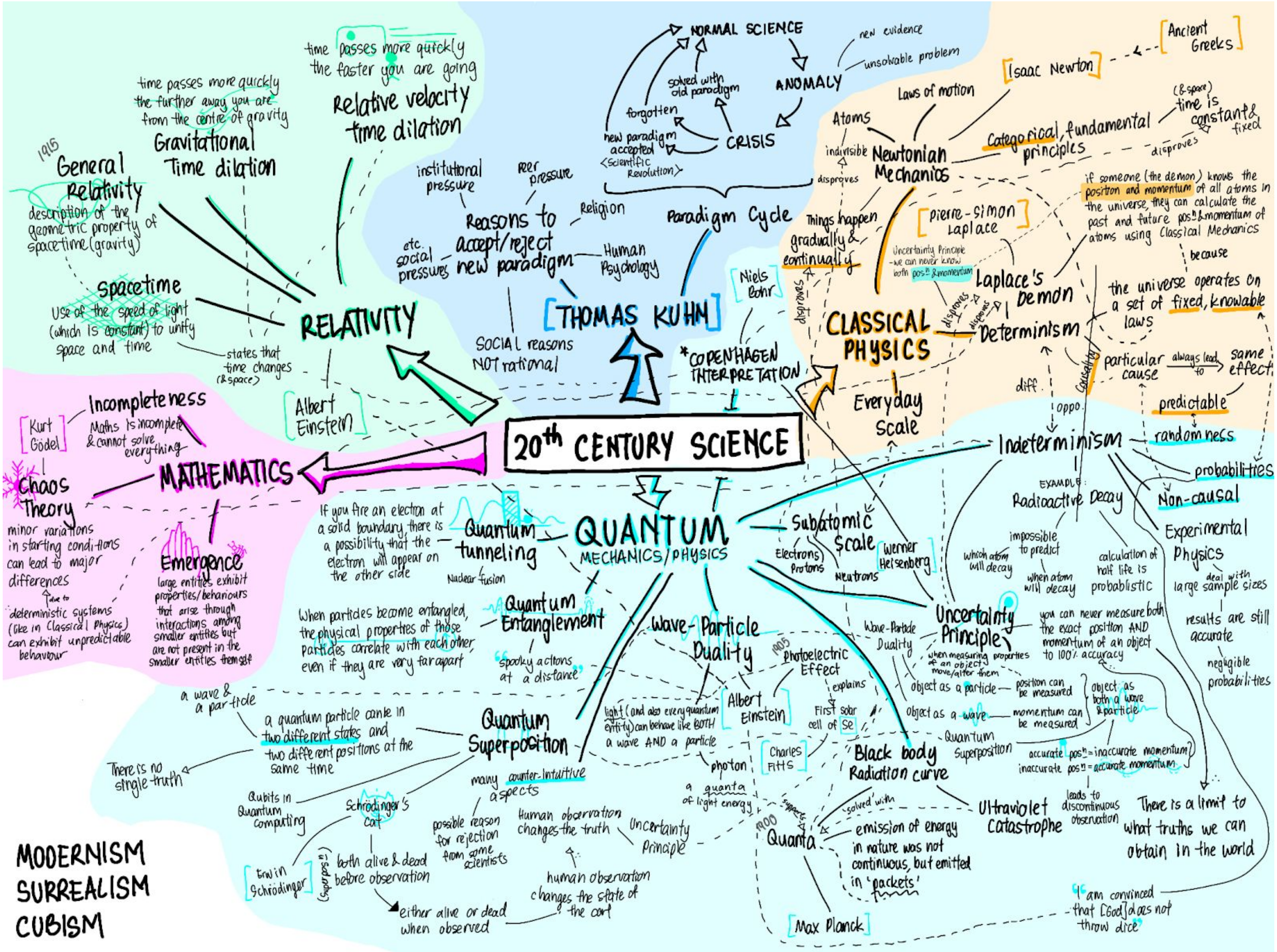
late 18th - 19th centuries

CONTENTS

TOP 10 IDEAS LIST with evidence of me slowly descending into a realm of insanity

Ideas, events, people and movements in 20th century science T.T

[20th-Century Science Mindmap.png]



Rank the top ten most important/significant findings

1. **Quantum Mechanics: Indeterminism**
    - Indeterminism is the idea that events are not caused deterministically due to the randomness and unpredictability of the universe; thus, ever event is probabilistic and non-causal
    - This idea is one that directly questions and opposes the fundamental concept of [determinism] that played an instrumental role in classical physics at that time; substituting the categorical, fundamental principles that governed the predictable effects of the universe with non-causal random outcomes of a probabilistic nature
    - It is the most important idea because it overturned the dominant deterministic view of classical physics where the universe is a fine-tuned machine that works uniformly with fixed laws with a view where the universe works in a randomised manner, governed by truths that are unattainable and predictions of events are merely probabilistic.
2. **Classical Physics: Determinism**
    - Determinism is an idea within classical physics which states that the universe operates on a set of fixed and knowable laws of causality, where a particular cause will always lead to the same effect; thus making the effect predictable
    - This has lead to the concept of Laplace's Demon by Pierre-Simon Laplace
        - According to determinism, if someone (the demon) knows the position and momentum of all atoms in the universe, they would be able to calculate the past and future positions and momentums of the atoms using Newtonian Mechanics due to the determinable, predictable

        nature of the atoms and thus know every event that happens in to every atom in the past, present and future.
        - There are various ideas within Quantum Mechanics that are directly against the existence of Laplace's Demon; namely, the Uncertainty Principle and Chaos Theory
    - Determinism is what drives the categorical, fundamental principles of Newtonian mechanics in classical physics and the belief that there is universal truth could be found.
    - This idea was important in the 20th century because it was the existing paradigm of that time which was being challenged by the ideas of indeterminism within the new, developing paradigm of quantum mechanics in the 20th century.

Classical Physics/Newtonian Mechanics	→	Quantum Physics/Mechanics
determinism	→	indeterminism
deterministic mathematics/the universe operates on a set of fixed and knowable laws; making everything calculable	→	probabilistic statistics
predictable	→	randomness
Causality: where a particular cause would always lead to the same effect	→	Non-causal outcomes

3. Quantum Mechanics: Wave-Particle Duality

- Wave-Particle Duality, developed through the work of various physicists including Albert Einstein, is the concept that every quantum entity, including light, can behave like both a wave and a particle
- The idea of Wave-particle duality was first brought about by Albert Einstein when he described the phenomenon that was occuring in the first solar cell: the Photoelectric Effect.
- Within the explanation, Einstein proposed a new theory where light could behave like both a wave and a particle; with a particle of light being called a photon and also being described as a quanta of light energy.
- Some interpretations of this concept state that every quantum entity can be both a wave and a particle at the same time. This relates to the idea of superposition in quantum mechanics.

4. Relativity

- The theory of relativity was developed by Albert Einstein
- Einstein's idea of spacetime, where the speed of light (which is constant) is used to unify space and time on a curved geometric plane, states that time and space change.
- This idea of spacetime is one that directly challenges one of the fundamental principles in Newtonian mechanics, which states that time and space are fixed constants.
- The acceptance of both Quantum Mechanics and Einstein's relativity could have been because both fields were in direct contradiction with the existing paradigm of Classical Physics
- If only one of the fields were of existence in the 20th century, scientists at that time could have still continued to side with Classical Physics' deterministic views. However, with various ideas from both fields questioning the existing paradigm's cornerstone (which is Determinism) and providing scientists with heaps of evidence, if not to accept the new paradigms but at least question the existing one, the two fields in existence together were able to wear down the Classical Physicists of that time and become quintessential to modern technology,

5. Quantum Mechanics: Uncertainty Principle

- Developed by Werner Karl Heisenberg, the Uncertainty Principle is a principle that states that you can never measure both the exact position and momentum of an object.
- This is because of the Wave-Particle Duality, which states that quantum entities can behave like both a wave and a particle. When an object is taken as a particle, the position can be measured by the momentum cannot and when the object is taken as a wave, the momentum can be measured but the position cannot. Even if the object is believed to be in a superposition state of both a wave and a particle, accuracy in the object's position cannot be achieved without compromising the accuracy in the object's momentum and vice versa. Therefore, an accurate value of only either the object's position or momentum can be obtained.

- It also states that one cannot measure properties of an object without moving or altering them. For example, measurement of the positional property of an object is obtained via the reflection of light against that object; however, if the light wave is too strong, it may ‘push’ and alter the position of the object). Thus, an accurate value of the positional property of the object can never be known.
- there are just some truths that can never be known.
- According to Heisenberg’s Uncertainty Principle, Laplace’s demon can never know the position and momentum of all atoms in the universe and thus can not know every event of the past, present and future. Essentially, the Uncertainty Principle proves that Lapalce’s Demon can never exist.

6. Quantum Mechanics: Superposition

- Quantum Superposition is the concept that a quantum particle can be in two different states and two different positions at the same time.
- Like many concepts of Quantum Mechanics, many aspects of it are counter-intuitive to our everyday, real-world experience. A famous thought experiment which captures its counter-intuitiveness is the thought experiment of Schrödinger’s cat, derived by Erwin Schrödinger, where a hypothetical cat is placed in a closed box with a radioactive substance that has a 50% chance of killing the cat. Schrödinger states that before the box is opened, the cat is both alive and dead, a superpositional state that is contrary to the binary of real-world experiences. However, when the box is opened, the can is revealed to be either alive or dead and not both because human observation changes the superpositional state of the cat. This idea that measuring or observing an object alters the object being measured is the Uncertainty Principle.
- The counter-intuitiveness of concepts like this is a possible reason for why some physicists reject certain theories in quantum mechanics or quantum mechanics altogether.

7. 20th-Century Mathematics / Quantum Theory >> Indeterminism: Chaos Theory

- A concept developed by Kurt Gödel, Chaos Theory states that minor variations in the starting conditions of a system can lead to major differences in the system’s outcome
- This idea demonstrated that what were initially thought to be deterministic systems, such as those in Classical Physics, exhibit unpredictable and therefore indeterministic behaviour.
- It also disproves the existence of Laplace’s Demon.

8. Quantum Mechanics: Quanta

- A quanta is the smallest incremental ‘packet’ of energy that is emitted by objects in nature.
- The discovery of quanta by Max Planck in 1900 was what caused the field of Quantum Mechanics to emerge and eventually displace the deterministic views of classical physics at that time as it disproved a fundamental principle of Newtonian mechanics; the principle that things happened gradually and continually.
- The discovery of quanta was further supported by Albert Einstein as he was describing the photoelectric effect with the idea of wave-particle duality; where light can behave like both a wave and a particle and that a particle of light, known as a photon, is actually a quanta of light energy.

9. Classical Physics: Newtonian Mechanics

- It relies heavily on the idea of determinism

10. Thomas Kuhn’s Paradigm Cycle

- Thomas Kuhn’s Paradigm Cycle describe the process of paradigm shifts, which lead to scientific revolutions
- A paradigm is a set of common facts, basic commitments, assumptions and methods by which scientists do research.
- Normal Science (everyday puzzle solving using paradigm) → Anomaly (new evidence or unsolvable problem) → Crisis (question current paradigm with uncertainty) → [1] New paradigm accepted [2] New evidence or unsolvable problem forgotten [3] unsolvable problem or evidence solved with or explained by old paradigm

Which ideas would you most expect to find in a source from that time period?

- Probably something about the tension between Quantum Mechanics/Relativity and Classical Physics in relation to Truth?
- Quantum Mechanics: Indeterminism VS Classical Mechanics: Determinism
- Quantum Mechanics: limitations to our ability to find truth//the truth does not exist//there is more than 1 truth VS Classical Mechanics: there is a truth and it can be sought

Here are a few tips. Think about the differences between the rigid 19th century classical physics governed by determinism and the indeterministic quantum mechanics of the 20th C. Also the swap from deterministic mathematics to the probabilistic statistics of quantum mechanics. Think about relativity and how it challenged old ideas of space and time. Think about the way that wave particle duality helps to question ideas about the reality of matter and how the seemingly non-causal nature of quantum physics messes up earlier assumptions that effects must always have causes

SECTION B PRACTICE

20th-Century Science [Practice Extract]

Albert Einstein, Extract from his letter to Max Born (1947)

Dear Born

If I were not a confirmed old rogue, with a fossilised bad conscience, I would not have been able to go for such a long time without writing to you…

I cannot make a case for my attitude in physics which you would consider at all reasonable. I admit, of course, that there is a considerable amount of validity in the statistical approach which you were the first to recognise clearly as necessary given the framework of the existing formalism. I cannot seriously believe in it [the quantum theory] because the theory cannot be reconciled with the idea that physics should represent a reality in time and space, free from spooky actions at a distance. I am, however, not yet firmly convinced that it can really be achieved with a continuous field theory, although I have discovered a possible way of doing this which so far seems quite reasonable. The calculation difficulties are so great that I will be dead long before I myself can be fully convinced of it. But I am quite convinced that someone will eventually come up with a theory whose objects, connected by laws, are not probabilities but considered facts, as used to be taken for granted until quite recently. I cannot, however, base this conviction on logical reasons…

I am glad that your life and work are fruitful and satisfying. This helps one to bear the craziness of the people who determine the fate of homo sapiens (so-called) on the grand scale. Maybe it has never been any better, but one did not see it as clearly in all its wretchedness, nor were the consequences of the bungling quite as catastrophic as under present conditions.

Best wishes to you and your family.

Yours

A. Einstein

You will be given four primary source extracts, one pertaining to each of the topics/time periods listed below. You will be asked to choose any **two** of the extracts. For each extract separately, you will be asked to:

a) [2 marks] Briefly *identify* the overall argument or position of the extract
   - This extract is a letter from Albert Einstein, a german-born physicist known for developing his theory of relativity, to Max Born, a german physicist who was instrumental in the field of quantum mechanics. The letter contains Einstein's arguments for rejecting Max Born's ideas about quantum mechanics, specifically about quantum entanglement as it substitutes the existing paradigm of deterministic events and categorical, fundamental principles from classical physics that Einstein believed in with notions of non-causal random outcomes of a probabilistic nature.

b) [3 marks] *Explain* at least three ideas that the extract contains, using brief quotations to show each idea; and
   - The most important idea in the extract is quantum mechanics, specifically quantum entanglement and the counter-intuitive, indeterminable nature of it that Einstein cannot accept.
   - Rejection to **quantum mechanics** - Quantum Mechanics: quantum entanglement and indeterminism
     - I cannot seriously believe in it [the quantum theory] because the theory cannot be reconciled with the idea that physics should represent a reality in time and space, free from spooky actions at a distance and not yet firmly convinced
       - "It" refers to Quantum Theory/Mechanics

        - “Spooky actions at a distance” is referring to Quantum Entanglement
        - Explanation of what quantum entanglement/quantum theory is?
    - Belief that truth can be obtained - Classical Physics: determinism
        - [convinced in theory] connected by laws, are not probabilities but considered facts
        - Einstein adheres to the belief that there are deterministic laws and fundamental principles that define truth and also that it is possible to achieve complete truth from the natural world
    - Rejection of paradigm due to social, non-rational reasons
        - I cannot make a case for my attitude in physics which you would consider at all reasonable.
        - I cannot, however, base this conviction on logical reasons
        - Einstein’s belief Classical Physics’ old paradigm that the truth can be obtained with categorical, fundamental principles and deterministic laws of cause and effect hinders him from accepting the new paradigm of Quantum Mechanics despite its evidence
        - Quantum Entanglement implied that some sort of communication that was faster than light happens between particles that are distant from each other - something that Einstein’s theory of relativity rules out
        - there is a considerable amount of validity
        - Einstein is kind of in denial?
        - He admits to the rational evidence that supports

c) [5 marks] Using the information in the extract and your broader knowledge, *evaluate* how important these ideas were in the time period in which the source was written
    - This was a possibly pivotal moment in the acceptance of quantum mechanics in science - the point in Kuhn’s model where people had 3 choices: Rejecting the new paradigm, forgetting about it or accepting the new paradigm
    - Einstein was a well known physicist at that time - if he rejected Quantum Mechanics with enough determination, many other people might have followed in his lead and rejected it too which would lead to yet another new paradigm being rejected due to irrational, social reasons that would then have to be revived decades later - which would technically slow down scientific progression

This extract is a letter from Albert Einstein, a german-born physicist known for developing the theory of relativity, to Max Born, a german physicist who was instrumental in the field of quantum mechanics. The letter contains Einstein’s arguments for rejecting Max Born’s ideas about quantum mechanics, specifically about quantum entanglement as it did not conform with his theory of relativity and substitutes the existing paradigm of determinism from classical physics that Einstein believed in with notions of indeterminism. Absolutely spot on. This is the perfect way to do step (a).

Einstein states that he is “not yet firmly convinced” and “cannot seriously believe in” quantum mechanics due its probabilistic nature and prefers a theory that is “connected by laws” and “considerable facts”. This probabilistic nature that he refers to is an idea in Quantum Mechanics called indeterminism. Indeterminism is the idea that events are not caused deterministically due to the randomness and unpredictability of the universe; thus, every event is probabilistic and non-causal. This idea is one that directly questions and opposes the fundamental concept of determinism that played a vital role in classical physics at that time; substituting the categorical, fundamental principles that governed the predictable effects of the universe with non-causal random outcomes of a probabilistic nature. Indeterminism is the most important idea in 20th-century science because it overturned the dominant deterministic view of classical physics where the universe is a fine-tuned machine that works uniformly with fixed laws with a view where the universe works in a randomised manner, governed by truths that are unattainable and predictions of events are merely probabilistic. Fantastic.

Einstein’s preference for a theory that is “connected by laws” and “considerable facts” demonstrates his adherence to the idea of determinism that is present in classical physics. Determinism is an idea within classical physics which states that the universe operates on a set of fixed and knowable laws of causality, where a particular cause will always lead to the same effect; thus making the effect predictable. Determinism was what drove the categorical, fundamental principles of Newtonian mechanics in classical physics and the belief that there is universal truth could be found. This idea was important in the 20th century because it was the existing paradigm of that time which was being challenged by the ideas of indeterminism within the new, developing paradigm of quantum mechanics in the 20th century. Good, but maybe could have used a bit **more detail**.

Additionally, Einstein also specifically rejects quantum entanglement “because the theory cannot be reconciled with the idea that physics should represent a reality in time and space”. Quantum entanglement is a concept which states that when particles become entangled, the physical properties of those particles correlate with each other, even if they are very far away and that knowing the state of one particle allows us to instantaneously know the state of the other. This concept suggests some sort of communication between the two particles that is faster than the speed of light; a suggestion that is Einstein's theory of relativity rules out. Excellent point. With various concepts in quantum mechanics and Einstein's theory of relativity being incompatible with each other, it is unsurprising that Einstein sides with his theory and describes concepts such as quantum entanglement as a "spooky action at a distance". Although the idea of quantum entanglement is not particularly important in the 20th century, it was still part of the growing new paradigm of quantum mechanics and the immediate contradiction between it and the widely accepted theory of relativity could have caused a widespread rejection to the field of quantum mechanics as a whole. Really great evaluation of importance.

Lastly, Einstein's argument against quantum mechanics being populated with more social reasons rather than rational, logical ones. This irrational thinking is also evident when Einstein states that there is a "considerable amount of validity" of quantum mechanics and even admits that he "cannot...base [his] conviction on logical reasons" yet is still against quantum mechanics. Furthermore, his argument against quantum mechanics is also rather ironic as he himself had contributed to the concepts of quantum mechanics such as wave-particle duality and supported the discovery of quanta at that time. Einstein's irrational rejection of this theory can be explained by Thomas Kuhn's argument that scientists accept or reject theories based on social reasons rather than rational ones; where Einstein is rejecting quantum mechanics because it is does not conform with his theory of relativity and because he was "old" and was less likely to take up the new theory as he had dedicated most of his work on the basis of the existing theory. These social reasons for rejecting quantum mechanics were important in the 20th century because if Einstein rejected quantum mechanics with enough determination, despite the irrationality in his arguments, widespread rejection of quantum mechanics could still have emerged at that time. However, it could have also been because of the irrationality in his arguments along with the awareness of irrational arguments slowing the emergence of new paradigms historically that lead people to not side with Einstein's social reasons and decided to allow the new paradigm to emerge instead. Great.

[LECTURE] 20th Century Science

Slides: 4 20th-Century Science Slides.pdf

CUE COLUMN Questions/Cues	NOTE TAKING COLUMN Key Ideas/Important Facts/Repeated (Stressed) information
Learning Goal	• Know something about 20th century science • Understand some of the social and non-rational processes involved in the change of scientific theories and have some idea of Kuhn's model of scientific change • [For exam] Understand some of the limits of human ability to know truth and some of the ways that there might not be single truth to know
PART 1: THE CHANGING TRUTH	
Science and Truth	• Truth changes over time and we are often slow to adopt • The question of truth and how it can be found has been an important one in Western history • Science has been an extraordinarily important part in the debate over how we find truth • Science is not the best example of Reason and truth • Science;s capacity to produce truth has not always been recognised or accepted by everybody • Even within science there is not universal agreement about what the truth is or how to find that truth in the natural universe • Sometimes disagreement caused by completely rational concerts, but sometimes there are other forces just as important and powerful as reason in the scientific process of generating truth • Truth, and how to get it, is often contested between science and society and within science itself

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<tr><td>Copernicus, Galileo and Heliocentrism</td><td>

CONCLUSION: the wider public and the church could not accept the ‘truth; that science had produced
Nicolaus Copernicus 1473-1543
Renaissance mathematician and astronomer
Put forward a cosmological model that place sthe Sun rather than the Earth at the centre of the universe - Heliocentric model
Ptolemaic System

Prior to Copernicus, the most widely accepted astronomical system was that of the Hellenistic astronomer Claudius Ptolemaeus
Known as Ptolemy
Geocentric model of cosmology derived from the work of ancient Greek philosophers like Aristotle

Copernicus

Outrages the church whose traditional cosmology was based around the writings of Aristotle, Ptolemy and the Bible
They insisted that Copernicus was wrong
The common sense argument that things would fall off Earth if were moving around the sun
The theological argument that the Bible said the Earth doesn’t move
For at least 100 years after Copernican theory, most scholars and churchmen continued to use the old geocentric system

The Copernican System

It wasn't until after the revival of Copernican theory by Kepler and Galileo that attitudes started to change, but it was by no means easy
Galileo Galilei, for example, not only revived for Copernican heliocentrism but challenged scholastic beliefs in other ways too
This helped people accept the heliocentric model
Despite the fact that Galileo had a good deal of evidence the church in 1616 banned Galileo from teaching or believing Copernicanism
He was then forces to publish a book that discussed the arguments for and against heliocentric
In this, he was expected to treat both theories equally but he did not
This angered the Pope and he was summoned to Rome and arrested
He was put on trial and put under house arrest for last few years of his life
It took decades after this for the heliocentric model to be accepted in Europe
For nearly 100 years people did not accept these; ‘truths’ produced by scientific enquiry despite all the supporting evidence

The New Truth

From a modern perspective resistance to Copernican ideas seems ridiculous
It would be extraordinarily difficult for people to alter their perception given such a long tradition
Here we see conflict between science and society
The really interesting point here is that what is considered truth, what is universally accepted as the truth, can change
Truth does not last forever

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<tr><td>Priestly, Lavoisier and Phlogiston</td><td>

CONCLUSION: there are competing ‘truths’ within science
Joseph Priestley (1733-1804)
English priest, natural philosopher, chemist and writer
Was famous for inventing soda water
At the end of the 18thcentury, chemistry was a new science
A central theory of the times was the Phlogiston theory of combustion
Phlogiston Theories of Combustion

Chemist at the time believes that the most important problem of

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chemistry was to understand combustion or why things burned
The Phlogiston theory of combustion argued that Phlogiston, an invisible substance, was the thing that caused combustion
So what made a piece of wood, for example, burn was the Phlogiston in it, and this Phlogiston would be given off during burning

Wood (Phlogiston rich) → Phlogiston in air + Ashes (no phlogiston)
A candle in a jar goes out because the air could only absorb a certain amount of phlogiston
When air had become completely phlogisticated it can no longer support combustion

Priestly had written a scientific paper about new pure kind of air he had discovered
He believed this air was dephlogisticated air, in other words, normal air that ha all of the Phlogiston removed
He demonstrated this dephlogisticated air to many people using experiments
Replicated the experiment for the French chemist, Antoine Lavoisier
Antoine Lavoisier

Was fascinated by Priestley’s experiment and continued to do research based on it
Announced the hypothesis that dephlogisticated air was the thing that made burning possible
It was not an invisible substance inside things like pieces of wood, it was something that existed in the atmosphere
Lavoisier called dephlogisticated air oxygen

Priestley refused to accept Lavoisier’s theory
Accepting the theory about oxygen meant replacing Phlogiston theory
Priestly continued to argue, along with others , that oxygen theory was wrong and kept using Phlogiston theory
Hs stubborn defence of Phlogiston theory led to him being called Dr Phlogiston

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CONCLUSION: Truths do not get immediately and universally accepted; truths change over time
Alfred Wegener
German polar researched, geophysicist and meteorologist
Became intrigued by the fact that animal and plant fossils on different sides of the Atlantic were identical
Argued that all the continents had in fact been joined together in one massive continent that he called Pangea - continental drift
The theory was not well received an the majority of scientists paid almost no attention to his theories for around 50 years
In 60s, exploration of the ocean floor lead to new discoveries which seemed to confirm Wegener’s hypothesis
Gradually, his theory attracted more and more supporters and today in its modified form as a theory of plate tectonics, it is the scientific consensus

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<tr><td colspan="2"><h2>PART 2: DOES NATURE RESIST A NOTION OF THE TRUTH [Particularly important for Section B]</h2></td></tr>
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Certain aspects of the natural world might not be able to have ‘truths’ formulated about them
Quantum Theory - the overthrow of Enlightenment ‘mechanism’
Relativity - ‘truths’ about the physical world are relative
Incompleteness (Godel to Wolfram) - No mathematical system can be universal
Chaos/nonlinear - some real world systems are not subject to prediction
Emergence - higher level ‘truths’ emerge in ways we can’t predict

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20th Century Physics	- One of the most exciting fields of science in the 20th century was physics - Beginning of century: the way we view reality was fundamentally changed by the development of quantum mechanics and theory of relativity - Together, these fields of physical radically challenged two ideas: - The idea that we could know the truth about nature - The idea that there is a truth to know in nature
The Rise of physico-mathematics	- One of the key stories of the scientific revolution is the change in the status of mathematics - The scholastics did not consider it part of natural philosophy. It was therefore not thought to correspond to the real world - With the new emphasis of mathematics provided by Neoplatonism, this began to change - Eventually became physico-mathematics, which was the belief that mathematics was the best way to understand the real world - Mathematical laws of nature that apply everywhere - A philosophy of nature - Matter is the same everywhere and when - Matter is made of atoms - Matter is inert - Matter acted on by non-material forces - The motion of matter could be explained by three laws (Newton's laws of Motion) ***Newton*** had not just described the law of planetary motion, but, using his ideas about the laws of matter and gravitation, had explained them mathematically - THis was the grand achievement of the physico-mathematics movement - The universe was like clockwork mechanism, dea inert matter that is moved by universal forces and which can be described mathematically - Newtonian mechanics is the starting point of classical physics - Classical physics describes the science of physics from the scientific revolution until end of the 19th century "Classical physics is the result of generalising and integrating into a coherent mathematical structure the results of experiments dealing in magnitudes not too different from those encountered in everyday life" "Implicit in the methodology of classical physics is the assumption that the laws suggested and verified by such experiments are of unbounded applicability" - Classical physics assumes that mathematical laws apply in all situations **Determinism** - The universe of classical physics is characterized by determinism ~ When you have a particular cause, the effects will always be the same - Pierre Simon Laplace - According to this idea, if you know initial conditions (the precise location and momentum (mass by velocity)) of every particle in the universe you can calculate all their future values (and even past values) fro the laws of classical mechanics
The Quantum Revolution	- At the turn of the 20th century deterministic classical physics faced a challenge from which it never recovered - Classical physics: knowable, predictable and calculable → Quantum Revolution: much stranger universe altogether - The quantum mechanics of the 20th century demonstrated that nature behaved completely differently at different scales - Classical physics: everyday scale → Quantum mechanics: atomic & subatomic scale - Max Karl Ernst Ludwig Planck - Discovered that the emission of energy in nature when observed on an

	atomic scale is quantized ○ He called these minute quantities of energy "quanta" ○ This discovery came from his work on black body radiation ○ A black body is a theoretical object that absorbs all possible radiation and re-emits all of it as energy ○ It has been used to help understand the relationship between temperature, wavelength and frequency ● The higher the temperature, the move visible light was present - black body radiation curve ● Various classical physics mathematical models could only capture parts of the real picture ● Some models could accurately describe the relationship between temperature and wavelength at low temperatures, while others could explain in high temperatures ● But no model could explain both ● Planck hypothesised that the emission of energy in nature was observed on an atomic scale was not continuous ● Energy emission occurred in extremely small, separate quantities. ● This meant that our experience of the world which tells us things around us is happening gradually and continuously (for example, changes in temperature) was false ● At the atomic level, things were not continuous but happened in small discrete jumps ● Max Planck revised the various mathematical models put forward to explain the black body radiation curve, but included the assumption that energy comes in quanta ● Assuming quantised energy, the new revised mathematical model perfectly agreed with experimental results ● This is known as Planck's law of black body radiation ● **CONCLUSION1: Planck had demonstrated that nature comes in packets and is not continuous (have profound implications)** ● In 1880s, Charles Fritts produced world's first solar cell using selenium ○ No one understood how the light hitting selenium could produce electricity ● Albert Einstein ○ According to Einstein, phenomena like the photoelectric effect ○ Einstein put forward the idea that light comes in both particles (photon) and waves ○ Proved that Planck's quantum theory was right ● The implications of quantum theory mean that we can no longer talk about the universe in the way that classical physics had done ● Quantum mechanics does not tell us categorically that a certain thing will happen ● When applied to subatomic particles, quantum mechanics can only tell us about probabilities, not absolutes ○ Example: There is a non zero possibility that if you drop your iPad, it might float up into the air ● Therefore quantum mechanics is indeterministic - exact opposite of classical physics ● Example: Radioactive decay - half life ○ A probabilistic calculation ○ It is impossible to predict which individual atoms will decay and when they will decay ○ Here, very much unlike classical physics causality is probabilistic and impossible to precisely identify ● However, this doesn't really prove to be much of a problem for most experimental physics

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● Most experiments are concerned with huge numbers of atoms and particles
● Therefore quantum mechanical calculations are incredibly accurate when talking about large systems
● Philosophical implications:
  ○ Given the unpredictability and randomness of radioactive nuclei, this means that we have no idea what causes an atom to decay
  ○ The decay of radioactive nuclei seems to have no cause
  ○ Quantum phenomena are indeterminate and non-causal (very unlike Classical Physics)
● Werner Karl Heisenberg - Uncertainty Principle
  ○ Demonstrated that when we know a particles' position we cannot know its velocity if we know its velocity, we cannot know its position
  ○ There are parts of nature that scientists just can not know
  ○ Opposite of Classical physics - which contained the assumption that we can develop certain knowledge of nature
  ○ Laplace's demon can NEVER KNOW THE INITIAL CONDITION
  ○ INDETERMINISMMMM
  ○ If we attempt to measure the properties of subatomic particle, we disturb and alter the subatomic particle
  ○ Classical physics agreed with this but thought that you could have a nearly infinitely small amount of energy involved (because energy could be infinitely divided)
  ○ Quantum mechanics proves that at least one quantum of energy must be involved in the process of measurement - the energy involved is significant
  ○ This means that the disturbance of the system is real and we are left uncertain as to the exact condition of the object we are measuring
  ○ A consequence of the uncertainty principle is that it becomes impossible to observe a particle continuously throughout a physical process
  ○ Observation is discontinuous
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<td>2 interpretations of quantum mechanics</td>
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<td>1</td>
<td>2 (Einstein: I am convinced that [God] does not throw dice)</td>
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● Quantum mechanics is the most complete description possible
● The behavior of individual sub-microscopic systems is intrinsically indeterminate, erratic and non-causal
● But the statistical laws of quantum mechanics give a seemingly regular and causal behaviour to ensembles of large numbers of sub-microscopic systems
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● The statistical description given by quantum mechanics is inadequate
● There exists a more fundamental and fully deterministic description, with respect to which quantum mechanics takes a position similar to the position help by classical statistical mechanics (of an ensemble of molecules) with respect to Newtonian mechanics (of the individual molecules)
● At present, we do not know this more fundamental theory, but it must exist, and we must search for it, since it is unreasonable to assume that there are phenomena not governed by
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	physical laws
Consequences of quantum theory: nontrivial quantum effects	● Wave particle duality ○ Light is both a wave and a particle ● Superposition ○ quantum particle can be in two different states at the same time and two different places at the same time ○ Schrodinger's cat: thought experiment ● Quantum entanglement ○ When particles become entangled the physical properties of those particles correlate with each other, even if they are separated by huge distances ● Quantum tunneling ○ If you fire an electron at a solid boundary, there is a possibility that the electron will appear on the other side ● Human observation changes the reality of the world
Other forms of physics in 20th century	● Relativity ○ Proved that Newtonian physics was untrue in many respects ○ Demonstrate that Newtonian concepts of absolute time and space were only valid in certain conditions ○ Proposed a radical new understanding in which space and time together formed a continuum which was curved - Space Relativity ■ Used the speed of light to unify space and time: spacetime ● General Relativity ○ Includes gravity, describing it as a geometric property of spacetime ● Gravitational time dilation ○ Time passes more quickly the further away from the centre of gravity you are ● Relative velocity time dilation ○ Time passes more quickly the faster you are going ● If an object is moving in space at 99% of the speed o f light, for every day it spends in space, 7 years would have elapsed on Earth
Conclusion thus far	● The revolutions in physics demonstrated that the Newtonian/classical physics view of the natural world was very imperfect ● Old ideas of truth are, once again, replaced by new ideas of truth - Truth changes over time ● It was beyond human ability to accurately know certain kinds of natural events ● 20th century physics put forward frightening evidence that the universe itself transforms and changes relative to gravity, speed, time and even observation by humans ● There is no single truth for us to know
Mathematics in 20th century	● Kurt Friedrich Godel ● Incompleteness ○ means that for all mathematical system there are valid equations (they play by the rules of the system) that cannot be solved ○ No mathematical system is universal. It can't describe everything ● Chaos Theory ○ Branch of mathematics that studies the behavior of dynamic systems ○ Demonstrates that such systems are extremely sensitive to initial conditions ○ Very small differences in initial conditions result in hugely different outcomes ○ This makes long-term prediction absolutely impossible

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- Example: snowflakes - everyone is different because they all have slightly different initial conditions

- There are many natural systems that we cannot know the truth about over time
  - Examples of chaotic systems: weather, fluid dynamics, turbulence, biological systems, social systems
- Stephen Wolfram
  - Where Newton used mathematics to describe the fundamental laws of nature, Wolfram argues that instead we should use simple computer programs, called cellular automata
  - He claims that mathematics is unable to properly model reality
  - Digital programs are needed to model a digital universe
- Insights provided by people like Godel and Wolfram in the 20th century upset long held beliefs about the relationship between mathematics and the truth of reality
- From the ancient Greeks to Issac Newton it has long been assumed that we can describe and understand the world accurately through mathematics
- Godel shows us that this is impossible
- Chaos theory shows us that many natural systems cannot be predicted
- Wolfram goes further and questions the usefulness of maths and the very nature of the universe
- Emergence
  - Process in which larger entities, patterns and regularities arise through interactions among smaller or simpler entities that themselves do not exhibit such properties
  - Example: termite mounds
  - Different kinds of truth appear at different levels in nature and these are not predictable

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PART 3: KUHN, REVOLUTIONS AND THE SOCIAL

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- Our acceptance, or not, of new truths is largely non-rational
- Kuhn and The Structure of Scientific Revolutions
- Why reason can’t always help to be certain about truth
- Theory change as a social process

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  - ‘Truth’’ in science changes over time
  - Why people do not accept new and better theories
  - Why do they insist on staying with old and inaccurate theories
    - Example: Einstein insist on classical physics interpretation of truth
- Thomas Kuhn
  - How changed science changed and why it changed
  - Argued that there has been a number of revolutions in science over history
  - Most important question: why do scientific revolutions occur when they do and why is there such resistance to new theories?
  - It was widely understood that science was a wholly rational pursuit
  - People believed that scientists accepted or rejected new theories based on evidence and reason
  - But, as we’ve seen in history of science, this does not happen
  - Why?
- Paradigms
  - A set of common facts, basic commitments, assumptions and methods by which scientists do research
  - A paradigm is basically a conceptual framework or theory
  - Kuhn says that there can only ever be a single paradigm in any

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	particular scientific filed ● Science is mostly puzzle solving - normal science ● However, sometimes a new piece of evidence emerges or a problem can't be solved using the current paradigm - Anomaly ● If the new piece of evidence can't be explained or the old problem continues to be unsolved - Crisis ● In a crisis, people begin to question the paradigm and people become very uncertain ● People try desperately to resolve the issue sometimes by proposing a new paradigm ● 3 ways out of a crisis ○ Solved using existing paradigm ○ Forget about it ○ A new paradigm is accepted - Scientific Revolution ● Why Reason Can't Help ○ The problem with induction - Inductive logic does not produce certainty ○ A particular set of facts can be explained by more than one theory ○ When scientist observes something, they always see it through the lens of their theory ● Why do people resist new, more accurate theories according to Kuhn? ○ Kuhn argues that scientists accept or reject theories based on **social reasons** ○ Younger scientists who have not spent as much time working with the old theory are more likely to take up the new theory - they are not as invested as older scientists who have dedicated lives to single theories ○ The acceptance or rejection of a theory is a social process, not a rational process ● Kuhn and Copernicus ○ If church accept Copernicus, it would weaken their power ○ Kuhn argues that there is a lot of emotional and institutional investment in following a particular scientific theory ● Kuhn and Priestly ○ When people become locked into thinking in a particular way, it is often very hard to change ● Kuhn and Wegener ○ Threatened the authority of experts and ideas about scientific progress ○ Experts are only expert in the current view - if there is paradigm shift, expert → beginner ● Conclusion of reasons ○ Human psychology ○ A person's religious belief ○ Peer pressure ○ Institutional pressure ○ Other Social pressures
Conclusion	● Discoveries in 20th century science have changed the way we see reality and truth. Newton's vision is dead ● There are limits to how much we can know ● There are not always truths to be known ● Mathematics cannot help us find the truth ● Reality is not always predictable ● Developments in 20th century science have shown us that there are limits to what we can know of the natural universe and that there may not be truths to know

	• Developments in 20th century philosophy have shown that some of the key processes in science are socialis, rather than rational • The 20th century made us understand that our relationship to truth is much more complicated than we ever imagined

[iBook] 20th Century Science	
Slides: 4 20th-Century Science Slides.pdf	
CUE COLUMN Questions/Cues	NOTE TAKING COLUMN Key Ideas/Important Facts/Repeated (Stressed) information
Learning Goal	• Know something about 20th century science • Understand some of the social and non-rational processes involved in the change of scientific theories and have some idea of Kuhn's model of scientific change • [For exam] Understand some of the limits of human ability to know truth and some of the ways that there might not be single truth to know

[iBook] Scientific Revolution	
Slides: 4 20th-Century Science Slides.pdf	
CUE COLUMN Questions/Cues	NOTE TAKING COLUMN Key Ideas/Important Facts/Repeated (Stressed) information
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The Scientific Revolution: Crash Course History of Science #12

- In what ways were ideas of truth challenged by the developments of quantum physics?
  - Before the developments of quantum physics, people thought that it was possible to achieve complete knowledge of the physical universe - basically the truth of the universe
  - However, developments of quantum physics disproved many fundamental principles and the deterministic laws of cause and effect from Classical Physics and showed that things do not behave in the mathematical, categorical, deterministic ways that had been through and instead worked in a more random, indeterministic manner with probabilistic outcomes. This therefore challenged the ideas of universal truth and even the ability to achieve truths from Classical Physics and proposed that there are many limitations to the number of truths we can know about the natural universe and that there are not always truths to be known
  - Categorical, fundamental principles → Probabilities
  - Deterministic laws of cause and effect →

20th-Century Science: Werner Heisenberg, Extracts from *Physics and Philosophy: The Revolution in Modern Science* (1958)

Coming back now to the contributions of modern physics, one may say that the most important change brought about by its results consists in the dissolution of this rigid frame of concepts of the nineteenth century [referring to classical physics (determinism, rigid principles, fixed laws of nature)]. Of course, many attempts had been made before to get away from this rigid frame which seemed obviously too narrow for an understanding of the essential parts of reality []. But it had not been possible to see what could be wrong with the fundamental concepts like matter, space, time and causality [Classical physics: Newtonian Mechanics] that had been so extremely successful in the history of science. Only experimental research itself, carried out with all the refined equipment that technical science could offer, and its mathematical interpretation, provided the basis for a critical analysis –or, one may say, enforced the critical analysis –of these concepts, and finally resulted in the dissolution of the rigid frame.

This dissolution took place in two distinct stages. The first was the discovery, through the theory of relativity, that even such fundamental concepts as space and time could be changed and in fact must be changed on account of new experience [Relativity: spacetime: states that time and space changes which disproves the fundamental principle in Newtonian Mechanics that time and space are fixed and constant].This change did not concern the somewhat vague concepts of space and time in natural language; but it did concern their precise formulation in the scientific language of Newtonian mechanics, which had erroneously been accepted as final. The second stage was the discussion of the concept of matter enforced by the experimental results concerning the atomic structure. The idea of the reality of matter had probably been the strongest part in that rigid frame of concepts of the nineteenth century, and this idea had at least to be modified in connection [modification being Wave-Particle Duality]with the new experience. Again the concepts so far as they belonged to the natural language remained untouched [reference to Correspondence principle Experimental Physics will still stay the same because it deals with large sample sizes]. There was no difficulty in speaking about matter or about facts or about reality when one had to describe the atomic experiments and their results. But the scientific extrapolation of these concepts into the smallest parts of matter could not be done in the simple way suggested by classical physics, though it had erroneously determined the general outlook on the problem of matter.