

I. THE UNIVERSITY AS AN INSTITUTION

Scientific Freedom

Wilholt* differentiates between freedom of ends and freedom of means:

- Freedom of ends: Scientists should themselves decide which research projects they pursue
- Freedom of means: The state or society must provide the resources required to conduct any research that scientists deem relevant to solve a particular problem.

Why should universities be allowed to have these liberties? This can be argued both through an epistemological argument and through a political argument.

EPISTEMOLOGICAL ARGUMENT

In summary:

Scientific freedom of research provides optimal conditions for our collective search for knowledge.

John Stuart Mill argued that scientific freedom is necessary because humanity is fallible: ideas that initially seem unreasonable may later turn out to be fruitful. Scientific freedom therefore allows science to develop without being bound too tightly by prevailing beliefs and unwarranted opinions. Thus it is possible for projects that would otherwise be discouraged to turn out to be fruitful.

The requirement for this to work efficiently is what is called Mill's asymmetry: falsehoods will be caught relatively quickly through mutual criticism, whereas truths will survive because accurate theories are difficult to falsify.

The epistemological argument requires that scientists are well informed about the happenings of the world, and hence also requires that there is freedom of communication.

POLITICAL ARGUMENT

* Torsten Wilholt (2010): Scientific freedom: its grounds and their limitations, *Studies in History and Philosophy of Science* 41: 174–181

This argument is based on the belief that citizens in democratic countries base, or at the very least partially base, their democratic decisions on science. That is, their worldview, and therefore their opinions, are strongly influenced by the research conducted by scientists.

This is outlined by Condorcet's report to the French legislative national assembly in 1792:

Finally, no public power must have the authority, not even the standing, to prevent the development of new truths or the teaching of such theories that contradict its particular politics or its present interests

Scientific freedom is central to democracy, and therefore it needs special protection. This argument is limited to the part of science that actually affects society and that which is discussed by the public.

Hvad vil vi med Universiteterne

Universities have two roles in society[†]:

- Research facility, to uncover technology and knowledge that allows Denmark to compete with the rest of the world
- Place of education for Denmark's future.

It is *not* enough to justify universities by their economic contribution to society.

SOCIAL ENGINEERS' ARGUMENT:

Universities do not produce enough innovation, nor enough candidates that are ready for the labour market.

FREEDOM FIGHTERS' ARGUMENT

Universities must be allowed to independently decide what research they conduct. The future's labour market is unpredictable, therefore universities must educate for any possible future.

The freedom fighters argue that fundamental research is what we should focus our efforts on, because it serves us in unpredictable ways. Therefore the financial

[†] Horst & Irwin (2018), Hvad vil vi med universiteterne, *Informations Forlag* 1: 15–25

support of research must be independent of the field of study – the universities must evolve independently of politics, religion and economy.

On the other hand social engineers argue that we must focus our efforts on applied research – problem-oriented research, where the more useful research receives the most funding. Our finite resources cannot be wasted on research that may never see the light of day. The social engineers focus on what can benefit society now, but research often takes time, and therefore it will affect a world different from the one we are living in now. Economic benefit cannot be planned with certainty.

The social engineers argue that Humboldt's idea of an isolated university (ivory tower), cannot be realised, because of the fact that universities need external funding, and therefore cannot be independent of democracy's interests.

Can Scientific Knowledge be measured by Numbers?

President Bush: "Science increases the general well-being".

The *Frascati Manual* is a set of standardised definitions that helps describe research and development, distinguish between different sectors, and measure personnel and expenditure devoted to each category. It stipulates how to define basic research, applied research, product development, etc.

Derek de Solla Price set up a way of quantifying science (number of employees, papers published etc.) and found exponential growth (1963). However, he predicted a sigmoidal limit: the development cannot continue exponentially because there are limited resources, including manpower.

Within academia success is measured by publication and citation numbers, the latter of which is quite difficult to measure.

Cole & Cole showed in 1967 that prestigious awards and positions were more commonly associated with high *citation* numbers.

However, there are no universally followed authorship protocols – sometimes gift authorship, courtesy authorship, etc. are given.

Vancouver guidelines for co-authorship:

- *Substantial* contribution to the conception or de-

sign of the work, or to the acquisition, analysis or interpretation of the data.

- Drafting or revising *critical* points.
- Final approval.
- Agreement to be accountable for *all* the work.

However, studies show that these guidelines are often ignored. Duplicate publication, gift authorship, and honorary authorship are examples of practices that undermine them.

There are different indices used to measure the worth of a scientist, for example the *h-index*, which is the number, *n*, of papers cited more than *n* times. This is too crude on its own. There are also other attempts at quantifying scientific worth, but all have their problems.

The number of citations are a measure for the *impact* of a paper/author, but not its quality. The number of publications is a measure of *quantity*, but not the quality. For example a result ahead of its time will receive little to no attention.

Lecture I

Humboldt's image of a university is a place where lecturers and students together search for new knowledge – research influences education and vice versa.

After the Second World War the sciences became more popular, because people began to realise that science improves general well-being.

UNIVERSITIES' CHALLENGES TODAY

Universities are experiencing increasing numbers of students, all of whom need to receive a good education. Their education has to prepare them for the labour market, but it is impossible to predict what the future labour market will look like.

Additionally the cost of research is increasing, because there are more and more research topics and groups. However, private financing also happens (QDev), which may affect the freeness of the research being conducted.

WHO SHOULD DECIDE WHAT RESEARCH IS CONDUCTED?

Universities are the highest institution for knowledge, therefore they themselves should decide what is im-

portant. On the other hand they are financed by society, so society should be able to decide what they want to get out of the universities in return for their financing.

Toulmin's theory of argumentation.

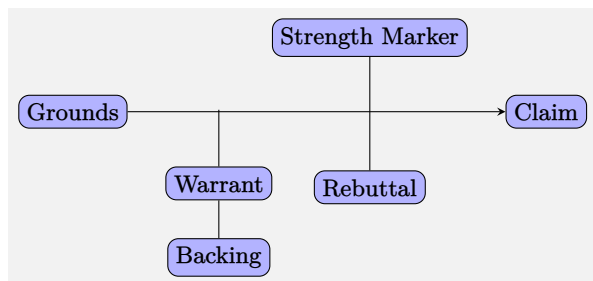


Figure 1: Toulmin's theory of argumentation.

This was used in Hanne Andersen's lecture to discuss the article on scientific freedom.

Drivsholm

Minister of research: "We devote funds to specific research fields, but do not influence what exactly is being done by the researchers, nor which technological progress should follow from the research." Hence the claim is that there is freedom of research in Denmark.

However, if you only fund the research that you deem relevant, then this goes against freedom of research. Thus it is not recommended to define too narrowly what the funds are intended to be used for. Additionally this could bias researchers towards politically attractive topics, preventing objective research – science is at its best if it is allowed to be free of excessive external influence.

The ivory tower does not exist, due to the fact that funds have to come from external sources. Therefore the minister of research in Denmark promotes freedom of means: the state provides the necessary funds, and the researchers themselves decide what research to conduct.

Hej Logik

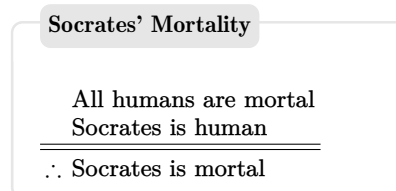
a priori: deduced from logical argumentation – a statement made *before* an experiment is conducted.

a posteriori: based on one's perception/measurements

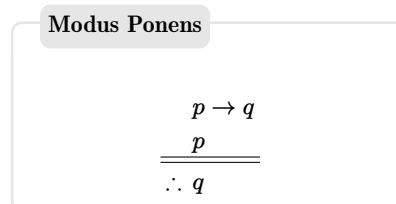
– a statement made *after* one has taken experimental data into account.

Classical logic concerns itself with arguments that can be expressed mathematically. Mathematical arguments consist of propositions (statements) that are connected using logical (binary) operators. Propositions have a truth value – they are either true or false.

If a conclusion can be made based off of propositions and their connectives, then the conclusion is reached *deductively*. Example:



More generally this type of argument (*modus ponens*) can be expressed using general propositions:



Naturally deductive conclusions can be made from more complicated arguments.

Logic only concerns itself with whether or not the conclusion follows from the premises, and not whether the premises are true.

II. METHODS AND MODELS

An Introduction to the Philosophy of Science

Scientists use and extend the cognitive abilities of humanity, and therefore science inherits the philosophical problems intrinsic to "ordinary knowers".

For instance, it is human nature to learn from experience, i.e. to generalise our knowledge based on experience of a subset of a quantity. For instance if you have only seen white swans in your life, you may be prone to state that "all swans are white". However, the process

of generalising from a subset is not, in general, valid, that is

$$\exists x \in X : p(x) \not\rightarrow \forall x \in X : p(x)$$

FALSIFICATION

Falsification is based on *modus tollens*:

Modus Tollens

$$\frac{p \rightarrow q \quad \neg q}{\therefore \neg p}$$

For instance Newton falsified the optics of old, by showing that a refracted image of the sun was not round, but elongated, which contradicts the prediction made by the optics of the day.

However, just because a theory has not been falsified, does not imply that it is true – perhaps the correct experiment hasn't been carried out yet.

DEMARCATION

According to Karl Popper “the criterion of scientific status is falsifiability”. However, this approach has its problems, due to *underdetermination*: for instance

Underdetermination

$$\frac{(p_1 \wedge p_2 \wedge p_3) \rightarrow q \quad \neg q}{\therefore \neg p_1 \vee \neg p_2 \vee \neg p_3}$$

There is no way of knowing which of the premises is false. For instance a scientific theory does not in and of itself imply experimental data; there are additional assumptions that must be made, and these may be wrong. Therefore it is not as simple to falsify a theory as Karl Popper makes it seem.

Additionally let us look at an example of unethical scientific practice that abuses underdetermination. Let us suppose that we have a theory that predicts that it rains every Monday. However, on Monday 5 April 2021 we see that it does not rain. Pure falsificationists would now dispose of the theory. However, we could make an *ad hoc* hypothesis and say: "it rains every Monday, except on 5 April 2021", avoiding the refutation of our theory, at least temporarily.

A less silly example of this is the geocentric picture of the universe, which predicted that all objects orbit the Earth in circular paths, with the Earth in the centre. However, the increasing accuracy of measurements allowed astronomers to measure that the orbits were not perfectly circular, and in fact occasionally the orbits would loop back on themselves. Had the followers of geocentrism been strict falsificationists, then their theory would have been refuted there and then. However, they added ad hoc hypotheses, namely epicycles, that helped "save the phenomena".

Finally, Einstein himself added an ad hoc hypothesis to his theory of general relativity. The theory in its original form allowed a dynamical universe, but at the time it was still believed that the universe was stationary, which led Einstein to add the Λ term to his equations. He did this because he wanted his theory to fit with the apparent data, and did not have an independent physical reason for it – the Λ was an ad hoc hypothesis. It later turned out that a cosmological-constant-like term is useful in modern cosmology, but Einstein did not know this at the time.

Generally it is said that ad hoc hypotheses are justified if and only if they can be justified independently of the theory.

Conjectures & Refutations (1945)

Karl Popper's demarcation criterion is the falsifiability of a theory. As examples Popper uses Einstein's theory of general relativity, Marx's theory of history, Freud's psychoanalysis and Alfred Adler's individual psychology. It appears that the latter three theories are excellent theories, because they explain a plethora of phenomena. However, due to this ability to describe apparently everything, there is nothing that can refute the theories, and this, according to Popper, is the weakness of these theories. By contrast, Einstein's theory of general relativity made audacious predictions, which would have refuted the theory had they been shown to be false.

Lecture II

The scientific method can, for example be separated into four steps:

1. Measurement
2. Theory based on 1.

3. Theory tested experimentally
4. If the experiment is successful, we use the theory as a foundation for future research

Or, alternatively, and perhaps more realistically:

1. Formulate a theory
2. Make predictions based on 1.
3. Test the predictions:
 - a. hold: the theory is backed
 - b. fail: the theory is refuted. Reformulate.

The latter of these approaches is referred to as the empirical method.

This process leads to an increase in knowledge. However, these models are criticised because neither describes the methodology used in all fields of science (none do). The critique of these models can be put into two categories:

- : *Descriptive*: The assumption that you always can create an experimental setup to test your theory does not hold. Sometimes failed experiments are due to failed design, and not falsified theories.
- : *Prescriptive*: It is possible for us to make the wrong logical conclusions. For instance we may think that, given a theory, it must be the case that we can measure some phenomenon. Not measuring this phenomenon may imply that our model is wrong, not the theory upon which the model is built.

Thus it is not enough to merely follow the steps to be a good scientist, each step must be contemplated.

FALSIFICATION AND VERIFICATION

Falsification as a demarcation criterion states that scientific theories must be falsifiable, and the more audacious the claims to be falsified are, the better.

Verification on the other hand states that theories are scientific if they have been tested successfully enough times.

Falsification is too strict: the cosmological principle (a homogeneous and isotropic universe on large scales) is difficult to test directly, and yet it has been extremely useful for the scientific community. Additionally, sometimes theories are still used by the scientific community

even after apparently falsifying observations, because the theory may remain useful within a limited domain or the auxiliary assumptions may be at fault.

Finally falsification oversimplifies reality, as we saw when discussing underdetermination.

Verification is, to put it bluntly, based on a fallacy:

Fallacy of affirming the conclusion

$$\begin{array}{r} p \rightarrow q \\ \underline{\underline{q}} \\ \therefore p \end{array}$$

More mature versions of verification are built on Bayesian statistics: the more often a prediction is found to hold, the higher the probability of a theory being correct. However, without Bayesian statistics verification suffers from the *problem of induction*, which states that we cannot from classical logic justify the conclusion from the premises.

Hume's formulation of the problem of induction goes something like this:

Every argument intended to defend induction is a circular argument

i.e. in order to justify induction in and of itself, we need to use induction. Therefore induction cannot be justified by deductive logic alone.

BAYESIAN STATISTICS

$$P(T|Ok) = \frac{P(O|Tk)P(T|k)}{P(O|k)}$$

The probability of a theory, T , being true, given an observation, O , and a context, k , is given by the probability of O given T and k , times the probability of T given k divided by the probability of O given k .

For instance the probability of light being bent by the sun without the theory of general relativity $P(O|k)$ is very small, therefore the probability of the theory being true given this observation is very large.

However, let T be a theory that agrees with every observation without making any observation more expected, hence $P(O|Tk) = P(O|k)$, which implies that $P(T|Ok) = P(T|k)$. What this means is that there exist no observations that can reinforce the theory.

Er det muligt at neutrinoer er hurtigere end lys?

Many physicists claim the experiment has errors and mistakes, merely based on an inductive argument: "The claim that c is the greatest speed has held up until now, therefore it should be on good grounds to assume that it is correct." But when must we take controversial data seriously then?

Physicists discussing this experiment usually fit into one of the following three categories:

- Orthodox: it must be a mistake
- Intermediate: trying to find instances where neutrinos moving faster than c can be unified with general relativity.
- Revolutionary: trying to develop new theories to replace general relativity

The majority of physicists are in the first group.

The forms of reasoning in science

Mendel: the ratio of dominant:recessive genes:

1st generation 2.96:1
2nd generation 2.81:1

generalisation: the ratio is approximately 3:1.

Kepler: hypothesise that planetary orbits are elliptical, which fits well with experimental data.

Both of the methods above agree with experimental data, however Mendel's method relies on an inductive argument, whereas Kepler's is a hypothetico-deductive method.

MILL'S CANONS

- : *Canon of agreement*: Let S_1 and S_2 be two instances of a phenomenon. $S_1 \cup S_2$ is the cause/effect of the phenomenon.
- : *Canon of difference*: Let S and P be instances of a phenomenon and the lack thereof respectively, then $S \setminus P$ must be the cause/effect/indispensable part of the cause.

Hence, by the canon of difference it can only be the difference in parent plants that causes peas to be different.

Mill's Canons do not describe the whole truth. For instance let us suppose we have a plant growing in a cold cellar, and one growing in the warm outside. We might conclude that plants thrive at high temperatures, however, what is really causing the outside plant to thrive is its access to sunlight.

INDUCTIVISM

: *Principle of Accumulation*: Scientific knowledge is the conjunction of well-attested facts.

: *Principle of Induction*: Inference from these facts to a deeper underlying truth about reality.

: *Principle of Instance Confirmation*: The more instances of observation of the law's prediction, the more plausible the law.

This is an attractive way of describing science. Scientists are seen as constantly adding knowledge to the database of scientific fact, and science is a self-sufficient body without contradiction.

However, scientists do not always agree on what is fact and what is falsehood. Additionally the principle of induction does not distinguish between two theories that explain the same data in different ways – this is combatted by a dubious *Principle of Simplicity* (basically Occam's Razor). Finally inductivism does not distinguish between a black-box and white-box theory, i.e. one that you feed numbers to and it spits out predictions, and one that makes a physical model that can be understood and grasped by human beings.

The meaning of Science

We can never be 100% sure that an experiment yields the true value due to experimental and statistical uncertainties – this makes falsification quite difficult. This is why we could rely on an inductive argument to criticise the Gran Sasso result.

III. THE DEVELOPMENT OF SCIENCE

Revolutions and Rationality

Different theories describe science differently, and in fact some theories contradict one another:

	Rational	Irrational
Inductive	Carnap	Hume
Non-inductive	Popper	Kuhn

Falsificationists (Popper), logical positivists, and logical empiricists (Carnap) tend to agree that:

- Science is cumulative.
- Science is unified, based on the same methodology and essentially reduces to physics.
- There exists an epistemological difference between the context of discovery and the context of justification.
- There is implicit confirmation or falsification in all scientific evaluations, independent of the individual.
- Sharp demarcation between science and pseudo-science
- Sharp distinction between observational terms and theoretical terms.
- Scientific terms have fixed and precise definitions.

KUHN'S REVOLUTIONARY HISTORY OF SCIENCE

- Abandoned beliefs are not unscientific, as they were acquired by similar methods as science.
- Science does not consist of a steady accumulation of knowledge. It often involves the wholesale abandonment of prior theories (paradigm shifts).
- Scientists' beliefs don't only determine which theories are created, but which theories are "confirmed".
- Confirmation bias

PARADIGMS & NORMAL SCIENCE

Within a paradigm scientists agree on the constituents of the universe, and how they interact. Thus there is some bias or subjectivity with respect to results that attempt to refute the current paradigm: it is difficult to disprove something if the tools you use are from the same paradigm as what you are disproving.

When scientists are educated they are taught about typical examples where the current theory worked well.

For instance the harmonic oscillator in quantum mechanics. Scientists are exposed to the same techniques and methodology in the hope that these methods can one day be applied to a new set of problems.

Science conducted within a paradigm is considered "normal science". The paradigm is extended and elaborated upon. Normal science is essentially problem solving using a fixed set of rules, decided upon by the current paradigm.

Anomalies, i.e experiments or results that contradict the basis of the paradigm, are at first ignored. Once they accumulate younger/maverick scientists will begin to think about new theories. Once a new theory is in place many scientists will begin to use it, if it is beneficial: a paradigm shift. There are different types of anomalies:

- Empirical data that contradicts a paradigm's central assumptions (the discovery of Jupiter's moons, lack of ether-wind, etc.)
- A theoretical solution that goes beyond the current paradigm (general relativity)
- When a problem contradicts the paradigm's ontological model.

Kuhn's theory of scientific revolutions disagrees with Popper's theory of falsification on the idea that the new theory simply builds upon the empirical content of the preceding theory, because paradigms may be incommensurable.

Paradigm shifts are unscientific or even irrational, because they require a leap of faith of the individual scientist and the scientific community as a whole.

THEORY AND OBSERVATION

New theories are not without presupposition, as it is inefficient to start from scratch every time you want to perform a new experiment.

We must distinguish between observables (heavy, red, wet, shiny etc.) and theoretical terms (electron, gravity, charge etc.). Observables are independent of theory, whereas theoretical terms are constructs of the theory. However, this independence is questioned by for instance Thomas Kuhn: "Seeing is not only having a visual experience; it is also a way in which the visual experience is had." i.e observation depends on circumstance and interpretations cannot be separated from measurement: the sunspots were only mentioned in Europe after the Copernican revolution, but had been seen by the Chinese long before.

Therefore competing paradigms are incommensurable. Some questions from previous paradigms are discarded, instead of being answered.

Kuhn argues that the following core values are common to all paradigms. A theory should be

- Empirically accurate within its domain
- Consistent with other accepted theories
- Wide in scope – not only explaining what it was designed to explain
- As simple as possible
- Fruitful → framework for ongoing research

Demarcation through the puzzle-solving nature of science and the aforementioned core values.

Science and Pseudoscience

The hard core of a paradigm is the basis upon which the entire paradigm is built. For instance the three Newtonian laws of motion and Newton's law of gravitation.

The hard core is protected by auxiliary hypotheses: *protective belt*.

In principle all scientific theories are born refuted and die refuted. Even general relativity was refuted – in fact it was refuted by Kaufmann the same year it was published.

Scientific theories have in common that they predict novel facts that were hitherto unimaginable or contradicted by rival theories.

Lecture III

Some theories are not discarded, when they have been refuted, which leads Kuhn to realise that there is more to scientific history than Popper and others cared to believe. Paradigms are built upon fundamental assumptions and theories, that are so central to the paradigm, that followers of the paradigm are not willing to give them up without a fight. One would rather change the protective belt, such that the paradigm doesn't need to be replaced.

It is only within a paradigm that data can be collected and compared, and that we can make theoretical models of it. The paradigm is the common foundation

upon which a field of study is built; it decides which experiments are worth conducting. Hence it is difficult to falsify the elements that are central to the paradigm, because the tools used come from the toolbox of the current paradigm.

DISCIPLINARY MATRIX

: *Symbolic Generalisations*: The paradigm's central mathematical equations and laws.

: *Ontological Models*: Paints a picture of the world, including its constituents and how they relate to and interact with one another.

: *Heuristic Models*: Refers to the values that a good (normal) theory lives up to.

: *Values*: Standard problems and exemplary normal science.

Paradigm shifts are sometimes more subtle than a complete overhaul of a theory. For instance the paradigm shift that occurred from the geocentric model to the heliocentric model did not change the mathematics, but it is the ontological model that changed, allowing followers of heliocentrism to make more accurate predictions.

In addition to the disciplinary matrix there are the so-called *exemplars* that serve as role-models for problem solvers. For instance the harmonic oscillator in quantum mechanics.

"Truth" is not well-defined during a paradigm shift. The scientific community's values and worldviews change, and therefore it is no longer straightforward to ask whether or not something is true. It is during the period where normal science is conducted that it makes sense to speak of truth, and it is also in this period where scientific discoveries are made, excluding the ones that cause scientific revolutions of course.

PARADIGM-DEPENDENCE

As mentioned previously, it is impossible to separate interpretation from the data-gathering process. Therefore depending on your view of the world during the data-gathering process, you will draw different conclusions based on the same data.

For instance Prout's hypothesis: "All atoms are groups of hydrogen atoms". This fitted very well with data in the early days, because many atoms have approximately integer masses in atomic units. Any deviations from this were said to be due to experimental error. However we now know that there are neutrons in the nucleus

and therefore different isotopes will have different masses but still the same number of protons. Thus experimental data in one paradigm can be reinterpreted in the new paradigm, and vice versa.

Another example of this, is the fact that it took scientists very long to understand the process of fission, even though they could very easily have made an experiment to accurately show it. This was because they could never have imagined that nuclei can radiate heavier particles than α -particles, never mind split into two approximately equal pieces.

Dark Energy, Paradigm Shifts and the Role of Evidence

The prediction of Neptune was an attempt to shield the Newtonian paradigm from falsification. An ad hoc hypothesis was made ("there exists an additional planet"), which was added to the protective belt, in order to prevent a paradigm shift.

However, this naturally does not always work. Scientists attempted to do something similar to explain Mercury's precession. This failed as they could not find the additional planet; we needed a paradigm shift (general relativity) to explain the precession.

There is no objective way of deciding whether the protective belt must be adjusted, or whether a paradigm shift is needed, in order to "save the phenomenon".

Λ CDM refers to the model where the universe consists of dark energy (accelerating the universe as per the Λ -term), cold dark matter as well as baryonic matter. However, we have yet to understand both dark matter and dark energy. The question is: can we adjust general relativity to explain these oddities, or is a newer better theory required? There's no way of knowing the answer to this question, until it has been answered.

Modern Cosmology

The cosmological principle states that the universe is homogeneous and isotropic on sufficiently large scales. However, this assumption is sometimes questioned, even though much of cosmology is built upon the cosmological principle. Discarding it would mean rethinking an entire field of physics. This would in turn imply that we would need to rethink the implications of modern-day cosmology, such as the evidence for dark matter, dark energy and the expansion of the universe.

However, the cosmological principle is difficult to test in a theory-independent way: in order to interpret the data that telescopes measure, we often already assume that some version of the cosmological principle holds.

Lise Meitner

The discovery of fission is credited to Otto Hahn, who received the Nobel Prize for it. Lise Meitner is only said to have played an important role in the discovery, but she received no official credit. There is evidence in letters between Meitner and Hahn that Meitner indeed played a *central* role in the discovery, and therefore she should arguably have been given at the very least a part of the prize.

Bombarding uranium with slow neutrons would result, according to Enrico Fermi, in a transuranium atom, which was thought to have the same properties as transition metals. However, this assumption was wrong, and therefore the data was interpreted incorrectly until Meitner's team found that the uranium had produced barium, which pointed towards nuclear fission.

IV. MATHEMATISATION OF PHYSICS

Geometry & Empirical Science

Mathematics distinguishes itself from the other sciences in that once a mathematical theorem has been proven, it will remain true. However, in the other sciences we can never prove a theory, and therefore we can only talk about the probability of a theory being true, or how well it has resisted falsification.

Mathematical theories are built upon *axioms*, which are essential assumptions that are required to build the framework of the theory. Thereafter everything within the theory must be shown to follow from these axioms. Thus mathematical theorems, t , are implications of the axioms/postulates, p_i :

$$(p_1 \wedge p_2 \wedge \dots \wedge p_N) \rightarrow t$$

The proving of a theorem does not make a statement of whether the theorem is true of the physical world, but of whether it follows from the axioms. Theorems are a way of expressing the information that is stored very densely within the axioms, in such a way that us mere mortals can understand and use it.

This implies that once the axioms are set, mathematical theories are completely independent of empirical

input: mathematics is *a priori*. Whether theorems apply to the physical world is a problem of empirical science, which depends on the interpretation of the more general/generic theory.

It is unfeasible or even impossible to directly measure whether axioms are true, or perhaps the question of whether they are true does not make sense to ask. The axioms are definitions that hold within the mathematical theory in question. We can change our axioms/theory if we want to describe a different physical object. For instance we are used to Euclidean geometry, but in order to describe spacetime we need non-Euclidean geometry, specifically pseudo-Riemannian geometry. This means we cannot use the old Euclidean axioms globally, but have to resort to a different theory. This does not mean that Euclidean geometry is false, but that it is not the suitable tool for describing curved spacetime.

Mathematics & Physics

Mathematics is the essential mediator between logical principles and the reality of nature; this was the excuse/motivation that Hilbert, Klein, etc. needed to convince themselves to follow a career in theoretical mathematics. For instance the vortex theory of atoms is very complicated mathematically, and it was primarily studied by mathematicians, and had little to no relation to empirical science: it was studied because it was interesting, and because of the challenges it presented, not because it was of any use to physics, even though it was born in physics. Minkowski and Hilbert believed that they could build physics upon mathematics – i.e. build a theory of nature on a foundation not influenced by empirical science but by pure mathematics.

Other mathematicians have a different point of view: mathematics is merely a tool that physicists (amongst others) need to describe nature, where the idea of a non-empirical theory of nature is impossible.

Unreasonable effectiveness of mathematics

Wigner discovered an incredible connection between a previously very theoretical part of mathematics: group theory, and particle physics. In this text Wigner discusses how incredible it is, that maths is so efficient at describing physical systems.

Galileo found that two objects fall at the same rate and land at the same time, which is unbelievable, because

it holds always and everywhere. But science is exactly about finding invariant quantities, and finding patterns such as this. Physics must be expressed in the language of mathematics, in order for us to be able to use mathematics to describe reality. Therefore, it is no wonder that mathematics is so efficient: physics describes the parts of nature that can be expressed mathematically.

Fra Aristoteles til Newton

PLATO

Science consists of forever true statements and describes unchangeable objects. The ideal theory is mathematics, and hence nature is to be described through mathematics.

ARISTOTLE

The ideal is biology, and science is the knowledge of *cause*. All movement is the realisation of the potential described by some biological system and the change from possibility to reality is what drives nature.

Heavy objects fly in straight lines downwards, whereas light objects fly in straight lines upwards, which defines a directional universe.

Heavenly kinematics is separate from earthly kinematics.

ARCHIMEDES: POSITIVISM

Mathematics is to be used to describe nature, without questioning the underlying mechanisms.

GALILEO

Galileo was not a positivist: he thought about what it was that caused the motion.

The philosophy of nature is written in the "great book", and it is written in the language of mathematics.

Lecture IV

PLATO

Nothing can be *known* about the physical world, because it is ever changing. However, there must be something deeper and constant which we can have knowledge about: the world of eternal forms. Therefore, empirical data is not worth studying.

ARISTOTLE

“Reality lies in the things”. Everything has a nature, and everything has its place in the universe. The universe consists of the earth in the centre and the heavenly objects orbiting it. Objects of earth fall towards the ground and objects of the heaven, such as fire, fly upwards. This is a *qualitative* model of the universe, as it cannot predict, for example, the rate at which things fall. However, this is not a problem, because no one asked the question “does this object fall faster than that one”.

GALILEO

“Aristotle’s theory did not make any *predictions*”. Galileo begins to mix empirical observation with theoretical modelling.

DESCARTES

Thinking substances: colour, smell, etc. are irrelevant for dynamics

Extended substances: mass, velocity etc. are relevant for dynamics

ISAAC NEWTON

There’s more to the universe than meets the eye: therefore we must use an objective tool to describe the world. Develops calculus to describe instantaneous quantities → changes physics forever.

“God is a pure mathematician”

IMMANUEL KANT

It is odd that thoughts conform to reality: we must interpret meaning or inscribe reality in such a way that our view of the world fits with reality. Our mind structures reality in such a way that we can understand and describe our surroundings.

HELMHOLTZ & POINCARÉ

‘Point’, ‘line’, ‘triangle’ needn’t refer to physical objects: we can abstract our mathematical theories from reality, so they can be generalised.

Mathematics climbs the ladder of abstraction, which trickles down to the world of physics. For instance mathematicians were writing about homomorphisms in a very general and abstract sense. However, homomorphisms can represent symmetry operations on a Hilbert space when looked at from the point of a view of a physicist.

WIGNER’S PARADOX

- The world is mathematical at heart (Realism, Platonism, etc)
- Yet the world is not mathematical, mathematics is merely a tool we can use to perform calculations.

so, *why* does mathematics describe reality so well? Mathematics is, after all a logical construction, yet mathematical concepts find applications in completely unrelated fields: symmetry groups in particles physics and Riemannian geometry in General Relativity.

How do we know that mathematical theories of nature are correct, especially those that are very abstract? Could Wigner have used a tool other than symmetry groups to do what he did in particle physics?

Idealisations in Physics

Idealisations are essential in physics, because without them it would be impossible to create mathematical models of reality that are simple enough to understand with our minds, or even simple enough to calculate numerically within our lifetimes. There are several different types of idealisations:

- : *Isolation*: Ignoring interactions with the surroundings
- : *Production*: Produce things in unnaturally high concentrations (for instance in a chemistry lab)
- : *Interpolation*: Taking a finite number of measurements and deducing what the complete data set might have looked like.
- : *Simplification*: Making slightly inaccurate assumptions that make calculations easier, but don’t affect the result too much (periodic boundary conditions in CMP)
- : *Neglect*: Ignoring higher order terms
- : *Theoretical idealisations*: For instance the harmonic approximation, which is not used because it is always exactly valid, but because it is often an analytic necessity.

However, the question remains of whether these idealisations describe reality. The answer to this depends on who you ask.

- : *Galileo*: Idealisations describe reality/ physical structures.
- : *Cartwright*: Idealisations don't include the entire truth, therefore they cannot describe reality.
- : *Essentialism*: Physical models abstract from complex circumstances and describe how a system would behave under ideal circumstances.

However, even though essentialists like simplifications/idealizations, it is not always the simplest approximation/model that is best. For instance assuming metals have perfectly periodic crystal structures would result in us believing they should have zero resistivity: we need the imperfections and thermal excitations to account for reality. This leads to the principle of *empirical adequacy*, which states that a theory may not be oversimplified so much that it lacks the description of empirical phenomena.

V. CONCEPT OF PROBABILITY

Atomfysik og Menneskelig Erkendelse

The uncertainty principle:

$$\Delta x \Delta p \geq \frac{\hbar}{2}$$

tells us that conjugate variables of quantum particles have inherent uncertainties that behave just like the Fourier transform uncertainty principle. This implies that if we measure the position of a quantum particle with some accuracy, say the width of a slit in a screen, then this will influence the particle's momentum. If the slit is small, then the uncertainty in the momentum will be large, which looks like the particle dispersing once it reaches the slit. Thus, if the slit is small enough, we will see an interference pattern on the screen, due to peaks and troughs in the probability of having different momenta – the position where an electron hits the photoscreen is related to its momentum at the slit. We must hence describe the motion as a wave, at least while the particle passes through the hole, and once it hits the photoscreen it behaves like a particle again: we measure a narrow peak in position when the particle hits the screen.

However, Einstein finds an issue with this description, at least if we want to interpret the description *ontologically*: if we describe it as a wave until it hits the photoscreen, after which it is a particle again, there must be some process that collapses the wave, or wave function, such that the position-probability distribution

is sharply peaked there where we measure its position. However, this process must occur at superluminal velocities, which is forbidden by special relativity.

A similar issue arises when we look at the double slit experiment. Let us imagine we measure the momentum of the particle, and thereby can calculate whether it passed (or will pass) through the upper or lower slit. However, irrespective of the technique used to perform this measurement, the act of measurement destroys the interference pattern. Thus we can either know which hole the particle passes through, or see the interference pattern. Here again we must allow the particle to behave like a wave in the intermediate stage of the experiment, to see the *particle* hit the photoscreen, with a distribution that corresponds to the interference pattern.

Bohr and Einstein's view of physics differed, in that the former required it to be an epistemological tool: something we use to perform calculations and make observable predictions, whereas Einstein wants physical theories to be ontological: they must describe the physical world and its constituents, as well as their interactions.

Clearing Up Mysteries: Background of EPR

Quantum mechanics is an empirical tool: it was discovered and developed through a series of experiments that did not conform to prior theories, requiring a scientific revolution. However, empirical theories have issues: there is no straightforward way of inferring ontological meaning from theories based on experiments. Additionally quantum mechanics does not make definite predictions, but rather probabilistic predictions; therefore an ontologist might claim that quantum mechanics, or at least its interpretation, is incomplete. Einstein and Schrödinger saw this as an intrinsic issue of the theory, whereas Bohr held that the theory is complete because it does make accurate predictions, even though they are not the kind of predictions Einstein and Schrödinger were looking for.

Einstein was involved and played an important role in the development of early quantum mechanics, but as he saw that the theory was becoming less and less ontological, he began to distance himself from it, trying restlessly to develop thought experiments that could contradict quantum mechanics' premises. However, these thought experiments were all solved by Bohr and his followers, almost exclusively using Heisenberg's uncertainty principle. Jaynes claims that this is a mistake: arguing quantum mechanics is correct by using one of

its results is a circular argument, and therefore it is no wonder that the thought experiments got nowhere in damaging quantum mechanics' foundation. "Bohr's foregone conclusion is always assured by his initial postulate, [...]"

Bohr and Einstein could never understand each other's arguments because the former was arguing epistemologically, and the latter was arguing ontologically. When Einstein says that quantum mechanics is incomplete, he means, as we saw in the previous section, that there is an issue with, for example, the collapse of wave functions occurring at superluminal velocities.

In an article in 1935 Einstein-Podolsky-Rosen objected to the claim of quantum mechanical completeness. Consider two systems in a superposition, for example two electrons that were previously in the ground state of helium (singlet). If we move these particles to great distances from each other, without removing the entanglement, one can perform a measurement of S_x on one electron, whereupon we can determine with certainty the value that S_x will give on the other electron, even if this information would have to propagate faster than the speed of light. Similarly we could have measured S_y on the electron and deduced the value that S_y would have given on the other electron. Note that S_x does not commute with S_y . Therefore EPR concluded that s_x, s_y must have existed before the experiment was conducted – a hidden variable of sorts.

John Stewart Bell continued to formalise the mathematics required to describe this, and in doing so, together with later experimental results, concluded that local hidden-variable theories cannot reproduce all predictions of quantum mechanics. Hence the values of s_x and s_y cannot simply be predetermined in the local classical sense. However, the hidden-variable theories discarded by Bell's theorem do not include all possible hidden-variable theories, something which is often ignored during discussion of this topic.

Introduction to QBism

Quantum Bayesianism agrees with the Copenhagen interpretation of quantum mechanics in that the concept of experience is central in the understanding of science. Unlike the Copenhagen interpretation though, QBism takes a *subjective* view of probability; "probabilities are assigned to an event by an agent and are particular to that agent". Probabilities are hence personal quantities, and not even 'certain' probabilities (0 and 1) are objective; they also depend on the agent.

The act of measurement does not, on this view, simply "read" out a pre-existing state from nature; it creates an outcome for an agent. The collapse of a wave function is the updating of the wave function because an agent has received additional information through experience. Additionally, QBism does not draw a fundamental distinction between interactions between quantum systems and classical systems and interactions between two quantum systems. Thus when Alice asks Bob a question, she can assign a wave function expressing a superposition of the possible answers Bob may give, which collapses when she updates the information available to her by receiving Bob's answer. Therefore experience differs from one agent to another, and outcomes do not exist for an agent before they have been experienced by that agent. What this means is that the EPR wave function does not collapse for Alice at the same instant in time that Bob performs his measurement, because this is not something that can be seen by Alice. Rather, once Bob and Alice compare their results, Alice receives information through communication that updates her electron's wave function, causing her to be certain about the state in which it is.

Statistisk Fysik

Addition Rule

$$P(A + B|I) = P(A|I) + P(B|I) - P(AB|I)$$

where the term $P(AB|I)$ is subtracted because $P(A|I) + P(B|I)$ double counts it.

Product Rule

$$\begin{aligned} P(AB|I) &= P(A|I)P(B|AI) \\ &= P(B|I)P(A|BI) \end{aligned}$$

Independence

For independent quantities, A and B it holds that:

$$P(AB|I) = P(A|I)P(B|I)$$

From the two expressions of the product rule we can derive Bayes' Formula:

Bayes' Formula

$$P(A|BI) = P(A|I) \frac{P(B|AI)}{P(B|I)}$$

Lecture V

The concept of probability evolved throughout the years, in the 15th to 16th century it was mainly used for games, for instance in Cribbage the *probability* of having a hand worth 28 is 1 in 216580.

In the 17th century Laplace writes about probabilities, and in fact derives Bayes' Law, even though it is attributed to the priest, Thomas Bayes.

The concept of probability evolved from a trick used to increase one's chances in games to a mathematical tool that would become central to quantum mechanics.

Bayesian probability can be used to formalise the concept of inductivism. Inductivism in itself is not a sound tool, logically. However we do learn from experience, and theories are said to be more valid if their predictions have been 'confirmed'. This can be seen in the following expression of Bayes' Law:

$$P(T|DI) = \frac{P(D|TI)}{P(D|I)} P(T|I)$$

where T is a theory, D is some data, and I is the initial information we have. What this gives us is an equation that tells us how to update the probability of a theory being true, once we have conducted an experiment that could have falsified it, but ended up giving the experimental result that the theory predicted.

QUANTUM MECHANICS

The central object in quantum mechanics is the wavefunction $|\psi\rangle$, which describes a probability distribution, for instance the probability of finding an electron at position x . The time evolution of this quantity is unitary, and can be expressed with the Schrödinger equation:

$$i\hbar \frac{\partial}{\partial t} |\psi\rangle = \hat{H} |\psi\rangle, \quad |\psi(t)\rangle = \hat{U} |\psi(0)\rangle$$

where $\hat{U} = \exp(-i\hat{H}t/\hbar)$. An observable is expressed as a Hermitian operator: $\hat{O} = \hat{O}^\dagger$, and the probability of the value o occurring is given by:

$$P_o = |\langle o|\psi\rangle|^2, \quad \hat{O}|o\rangle = o|o\rangle$$

DOUBLE-SLIT EXPERIMENT

Let $P(x|I)$ be the probability of observing the electron at the position x on screen. It is clear that $P(x(S_1 + S_2)|I) = P(x|I)$, where S_i is the probability that the electron passed through the i^{th} slit, because $(S_1 + S_2)$ is a tautology (the electron *did* pass through one of the slits). Thus using the distributivity of propositionals, as well as the addition rule, we find that

$$P(x|I) = P(xS_1|I) + P(xS_2|I) - P(xS_1S_2|I)$$

however the last term is zero *classically*, because the electron cannot pass through both slits simultaneously. Using the product rule we can write

$$\begin{aligned} P(x|I) &= P(S_1|I)P(x|S_1I) + P(S_2|I)P(x|S_2I) \\ &= \frac{1}{2} (P(x|S_1I) + P(x|S_2I)) \end{aligned}$$

this tells us that we would expect a superposition of two normal distributions on the photoscreen. The quantum mechanical description is slightly different, because the probability amplitude associated with the wave function passing through both slits simultaneously is nonzero. Suppose we put another particle at one of the slits, such that if the electron passes through that slit the measurement particle will transition $|\phi_0\rangle \rightarrow |\phi_1\rangle$, and if not, then the measurement particle remains in $|\phi_0\rangle$. The probability of finding the electron at x will hence be

$$\begin{aligned} P(x) &= |\langle x|\psi\rangle|^2 \\ &= |\langle x|\psi_1\rangle|^2 \langle \phi_1|\phi_1\rangle + |\langle x|\psi_2\rangle|^2 \langle \phi_0|\phi_0\rangle \\ &\quad + \langle x|\psi_1\rangle \langle \psi_2|x\rangle \langle \phi_0|\phi_1\rangle + \langle x|\psi_2\rangle \langle \psi_1|x\rangle \langle \phi_1|\phi_0\rangle \end{aligned}$$

where $|\phi_i\rangle$ is the state of the measurement particle correlated with the electron's path. The last two terms are interference terms, corresponding to the quantum contribution from the electron not having a definite classical path. If $\langle \phi_0|\phi_1\rangle = 0$ we return to the classical result, because then we can, once again, with 100% certainty determine which slit the electron passed through.

Bell's discussion of the EPR paradox supports the conclusion that, at least for local hidden-variable theories, physical properties cannot simply be treated as predetermined values that are revealed by measurement.

VI. ETHICS AND VIRTUE

Normative Ethics

Ford hurried the production of the Ford Pinto so that they could compete with smaller European cars. The

issue was that the fuel tank presented a hazard, as it was not protected well enough, implying that a crash from behind could result in an explosion. The company did a cost-benefit analysis, comparing the expected legal costs of deaths and injuries with the additional cost of changing the position of the fuel tank (11\$ per car), and decided it was not worth the hassle. In a court case where Ford was being prosecuted because of the death of four teenagers, they were found not guilty, even though Ford knew about the issue and decided not to warn their customers. To discuss this we need to introduce different terms:

- : *Morality*: Totality of opinions, decisions and actions with which people express, individually and collectively, what they think is good and right.
- : *Ethics*: The systematic reflection of morality.
 - : *Descriptive Ethics*: The branch of ethics that describes existing morality, including customs and habits, opinions of good and evil, responsible and irresponsible behaviour and acceptable and unacceptable action.
 - : *Normative Ethics*: The branch of ethics that judges morality and tries to formulate normative recommendations about how to act or live: more subjective than descriptive ethics.

UTILITARIANISM

Now we will continue to discuss *utilitarianism*[‡], which is an ethical consequentialist theory that focuses on the consequences of one's actions. Specifically, utilitarianism measures consequences as the increase or decrease of happiness, pleasure and welfare of humanity as a whole.

John Stuart Mill later refined this ethical theory by arguing that intellectual pleasures are worth more than physical/animal pleasures. He introduces the *freedom principle*: an agent is free to improve his/her own level of happiness, as long as this does not result in a negative effect on others' happiness levels.

Utilitarianism can be criticised on numerous counts; for instance, it does not necessarily allow for "distributive justice", which is the value in having certain goods distributed across the entire population, such as income, happiness and career opportunities.

[‡] Founded by Jeremy Bentham

KANTIAN DEONTOLOGY

Deontology refers to the part of ethics that focuses on an agent's duty. The individual should be able to decide whether an action is ethical or not based on logic, fundamental principles and duties that are specific to the agent. Kantian deontology continues to specify how an agent is to decide whether an action is ethical. This is to be done through the *categorical imperative*, which has two equivalent formulations:

Universality Principle

Act only on that maxim which you can at the same time will that it should become a universal law.

Reciprocity Principle

Act as to treat humanity, whether in your own person or in that of any other, in every case as an end, never as a means only.

However, in cases where you are given two choices, both of which break the principles, Kantian deontology cannot tell you which action is more ethical. For instance, a sociopath with a knife knocks on your door and asks whether your son is home. If you tell him the truth you know that your son will be stabbed to death, so you will have allowed a death to happen. But if you tell him that your son is not home, then the sociopath will leave, but you will have lied to him. To our everyday ethical decision-making skills this problem is trivial; however, Kantian deontology cannot give us a solution.

Another problem is presented by situations in which the right decision has harmful consequences. For instance, freeing zoo animals may seem to be the ethical thing to do, because it is wrong for them to be caged in. However, having most likely been raised in captivity, the newly freed animals may be unable to catch their own prey/find their own food, which will most likely kill them. Therefore, both freeing and not freeing the zoo animals can appear wrong in different ways; however, Kantian deontology may still state that the animals must be freed.

Etiske Perspektiver

Nagel attempted to unify deontology with utilitarianism. He does this by distinguishing between agent-neutral and agent-relative values:

- : *Agent-neutral values*: objective values that aren't dependent on one's personal perspective. For example happiness, good health, lack of hunger, etc.
- : *Agent-relative values*: subjective values, such as having time to do a specific hobby.

Utilitarianism focuses on the agent-neutral values, particularly the happiness of the entire population.

However, there are (at least) three additional ethically relevant forms of reasoning that are based on agent-relative values: autonomy-based reasoning, deontological reasoning and reasoning based on special obligations.

Agent-neutral values are said to trump agent-relative values, but never the other way around.

Lecture VI

Kantian deontology and utilitarianism are still relevant ethical theories today, even though they both have their issues. It is important to be aware of these issues when one applies the theories to problems.

There is a difference between an ethical action and a legal action. Usually laws are made to ensure people behave ethically; however, it is not always the case that the law covers a particular problem. For instance, something that is relevant to us would be the development of new technology or theories that may be used for unethical action. The law does not always tell us what or what not to do; therefore we should use ethics to guide us in these cases. For instance, what would you have done, had you been asked to work on the Manhattan project? There was nothing stopping one from doing it legally; however, one might argue that the sole purpose was to create a new kind of killing machine, which by many accounts is unethical.

ADDITION TO UTILITARIANISM

Rule utilitarianism is a form of utilitarianism where you do not make ethical choices at each action, but instead base your actions on a set of rules that are said to increase overall happiness.

"EXCUSES" TO IGNORE ETHICS

- : *It's not illegal*: This does not hold by itself, because laws are made by humans, and humans are fallible. Therefore one should not let legality replace one's ethical decision making.

- : *I'm not responsible for what it was used for*: By developing/designing instruments/technology/etc. one has a responsibility either to make misuse/abuse difficult or at least to educate the population on proper use.
- : *Not knowing what it could be used for*: This can actually hold, but only to a certain extent, because the previous point implies that we are responsible for thinking about possible consequences.

UNETHICAL BEHAVIOUR IN SCIENCE

Fabrication of data, falsification, and plagiarism, both on purpose and through negligence.

To prevent this from happening, the scientific community uses a process called peer review, where articles are only published if they have been approved by a board of peers. This is based on a principle called collective scepticism, which is said to increase productivity and decrease unethical behaviour. However it is not always clear whether the peer-review board can be trusted, or whether they do their job correctly; they themselves may be negligent.

However, despite these preventive measures, there are cases of unethical behaviour in science that are not caught for years, and that could in principle lead a field of research astray.

A question that arises in this context is whether or not the co-authors bear responsibility when one of the authors, for example, fabricates data. Should they have checked that the data is real? Normally each author is responsible for their part of the project, and mixing roles would be quite inefficient. Usually you have no reason to believe that your co-author is behaving unethically.

However, a less extreme instance of unethical behaviour is 'questionable practice' in science, for example not checking your code sufficiently and publishing nonsense results.

The reasons that cause people to act unethically include:

- *I know the truth*: a scientist believes that they know what the experiment will show, and therefore needn't waste time actually getting the data.
- *Ignorance*
- *Structural pressure*: Especially junior scientists are required to publish a number of papers during

a predefined amount of time, which causes stress that may lead scientists to act unethically.

- *Wanting to get a specific result*

VII. RISK AND CAUTION

Ethical Aspects of Technical Risks

- : *Hazard*: Possible damage or undesired effect
- : *Risk*: specification of hazard. Product of probability of occurrence and the effect thereof.
- : *Safety*: Absence of risks and hazards, at least to an extent that usage is reasonable and desirable. Related to the notion of ‘acceptable risk’.
- : *Uncertainty*: Lack of knowledge: known effects but unknown probabilities of these effects occurring.
- : *Ignorance*: Lack of knowledge: refers to the situation where we do not know what we do not know (unknown risk).

Equal risks aren’t necessarily equally acceptable; consider

- : Risk A: 0.0001% risk of killing 1 million people.
- : Risk B: 0.1% risk of killing 1000 people.

The product of probability and effect is the same in these examples, but it is not the case that both risks are equally acceptable.

Informed Consent: Activities are acceptable if participants are aware of and have consented to the possible risks.

Lecture VII

CONSIDERATION WITH RESPECT TO ACCEPTABLE RISKS:

- Are the people in question aware of the risks, and have they consented to them?
- Do the possible benefits due to success outweigh the repercussions due to failure?
- Are there alternatives that are more beneficial or less risky?

- Are the positive and negative consequences evenly distributed?

We define two types of errors that are made during risk assessments:

- : *Type-I error*: Assume a statement is true, when it in fact is false.
- : *Type-II error*: Assume a statement is false, when it is true.

For instance, a country may not prepare the relevant preventive measures against coronavirus, because it is under the impression that coronavirus is a hoax. This is an example of a type-II error while assessing the risk posed by coronavirus.

Scientists on Trial: at Fault?

The earthquake in L’Aquila, Italy, in 2009 killed 300 people. After hundreds of tremors up to roughly magnitude 3.8, officials stated that the more small earthquakes occur, the lower the probability is of a major earthquake occurring. The subsequent earthquake had magnitude 6.3, killed 300 people, injured 1500, destroyed 20000 buildings and left 65000 people homeless.

The scientists in question were put on trial for negligence: they should have done more to save lives, and to communicate their knowledge on the earthquakes to the general public. They should have been more cautious, and not allowed people to put down their guard.

VIII. EXAM

The Disputed Birth of Buckyballs [1]

Harry Kroto, at the time of writing of the article, is a spectroscopist at the University of Sussex in Brighton. He was the driving force behind the experiment that led to the discovery of buckminsterfullerene.

Richard Smalley, who was a chemist at Rice University in Houston, created the machine that would be used for the aforementioned experiment. The apparatus, a so-called laser-supersonic-cluster beam apparatus, consists of an adjustable laser and a supersonic jet of inert gas that can be used to suspend atoms such that they form clumps.

Bob Curl, an old friend of Kroto's and a colleague of Smalley's, had told Kroto about the apparatus, and he was immediately fascinated by its potential. Kroto was shown the machine, and he wanted to use it to simulate the dense, carbon-rich winds blowing from giant stars; however, Smalley and his team had other projects they were busy with, so this research plan did not suit them. After about a year of back-and-forth Smalley finally agreed to collaborate with Kroto in August 1985. Smalley was reluctant, especially because his competitors had made recent progress, and he wanted to "horn in on the carbon act".

The mass spectrometry they were using to measure the masses of the molecules made by the apparatus showed an unexpected peak at the mass corresponding to almost exactly 60 carbon atoms. This was buckminsterfullerene, which they would only figure out a few days later. Buckminsterfullerene is a molecule that consists of 60 carbon atoms arranged in a truncated icosahedron, which is an arrangement of hexagons with dispersed pentagons that allow for the curvature.

The dispute arises in the scientists' accounts from this point. They were at first imagining the molecule to be planar and graphite-like; however, quite soon they had two competing models. The molecule was shown to be inert, which implied that it could not have any bonds floating about. This led them to the idea that it was spherical, or that it was planar with the bonds folded inwards. The molecule was stable – they could in some instances produce it in concentrations 40 times greater than any of the other molecules.

Neither Smalley nor Kroto had the immediate claim that it was a truncated icosahedron; it was a gradual process that seemed to involve all parties. Kroto, however, claims that he introduced the concept during the discussion, which he had known for many years because he was a graphical artist in his free time and was interested in Buckminster Fuller's work on "geodesic domes". Smalley disagrees that it was purely Kroto's idea. He claims that it was just mentioned in discussion, but not that it was anybody's individual idea. He also claims that no one was fully convinced of the idea until he the next morning threw a model of the ball onto the table. Kroto claims that Smalley looked at it with surprise/realisation, seeing what it was and that it fit their specifications. However, Smalley claims that the look in Kroto's eyes was *recognition*: that this indeed was the ball that Kroto had modelled for his children at home.

This disagreement soon began to ruin Kroto and Smalley's relationship. Smalley at first didn't give Kroto co-authorship, however, after a discussion he agreed that

it is appropriate for him to be named as co-author. However, Smalley required Kroto to come to the USA regularly, if Smalley was to continue to name Kroto as co-author. They both agree that the disagreement was a pity, and that it ruined an otherwise fruitful and successful academic relationship.

Hvor sikkert er det at benytte nanoteknologi i hverdagen? [2]

We use nanoparticles in many different parts of our everyday lives. We use them in the food industry to prevent mould, and in sprays, cosmetic products, clothing etc. In fact, some suggestions have arisen in the scientific community about whether they can be used for vaccinations.

Do they pose a threat to our health? They are small enough to penetrate our skin, and to sink all the way to the very bottom of our lungs, where the body's natural cleaning system can't reach. Jacek Fiutkowski, a scientist at CheckNano who investigates the health risks of using nanoparticles in our everyday lives, states that there quite fundamentally is a risk associated with nanoparticles, simply because of their tiny size. If the nanoparticles additionally are toxic to your body, then they are very dangerous, because they can't be seen or smelled or felt, and they enter your body very easily.

However, the dangers stated by Jacek may be exaggerated, because his experiments were conducted in a laboratory, where the concentrations are much higher than they will be in usual use cases. Additionally many relevant nanoparticles deteriorate in air within 24 hours, which minimises the threat further.

However, for example the silver particles used in the food industry to prevent fungal and bacterial formation have been shown to have a toxicity that depends on their concentration as well as their size. It is currently unknown to what extent the nanoparticles from packaging are absorbed by the human body, and therefore it is still unknown whether these particles pose a threat.

Det Nationale Forskningscenter for Arbejdsmiljø primarily focuses on contact with nanoparticles through physical touch and through inhalation. They state that the rate at which nanoparticles can enter your skin is negligible, and therefore the relevant risk factor is the inhalation of nanoparticles. The risk is due to the fact that these tiny particles can sieve down through the lungs into the alveoli, where coronavirus also resides once infected. This can lead to infection and 'acute-

phase response’.

Therefore, the takeaway from the article is that we should be cautious of our use of nanoparticles, and that we, especially when in contact with aerosol nanoparti-

cles, should wear the proper protective equipment and be sure to minimise our intake of nanoparticles through inhalation, especially in spray products. Perhaps it is best to use them outside with our backs to the wind, or not to use them at all.

[1] The disputed birth of buckyballs.

[2] Hvor sikkert er det at benytte nanoteknologi i hverda-

gen?