The Israel Academy of Sciences and Humanities

Albert Einstein Legacy
A One Hundred Years Perspective

ABSTRACTS

10 – 13 April 2005

Jerusalem

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PROGRAM

Albert Einstein Legacy - A One Hundred Years Perspective

Sunday, April 10

20:00 **Opening and Greetings**

Chair: Prof. Alexander Levitzki
Chairman of the Natural Sciences Division,
The Israel Academy of Sciences and Humanities

Greetings: **Prof. Menahem Yaari**
President, The Israel Academy of Sciences and Humanities

Introduction: **Prof. Raphael D. Levine**
The Hebrew University of Jerusalem

Albert Einstein Memorial Lecture

The Einsteinian Perspective

Prof. Sir Roger Penrose
Oxford University

Monday, April 11

9:45 **Greetings: Mr. Moshe Katsav**
The President of the State of Israel

10:00 - 12:15 Session 1. Broadening Horizons of Physics

Chair: **Prof. Joshua Jortner**
Tel-Aviv University

10:00 - 10:45 The View Behind the Kelvin Clouds

Prof. Yuval Ne'eman
Tel-Aviv University

10:45 - 11:30 Einstein and the Quest for a Unified Theory

Prof. David Gross
University of California, Santa Barbara

11:30 -12:00 Discussion

12:00 -12:15 **Musical Interlude**

LUNCH

13:00 - 15:00 Session 2. Cultural and Political Aspects

Chair: **Prof. Ruth Arnon**
Vice-President, The Israel Academy of Sciences and Humanities

13:00 - 13:45 The Emergence of the Einstein Phenomenon: Reconciling Science, Politics, and Personal Identity after World War I

Prof. Diana Kormos Buchwald
California Institute of Technology

13:45 - 14:30 Einstein and Relativity in the Context of Weimar Culture

Prof. David Rowe
Johannes Gutenberg University, Mainz

14:30 -15:00 Discussion

15:00 - 15:20 **Coffee**

15:20 - 17:30 Cultural and Political Aspects

15:20 - 16:05 Einstein Recovers Judaism and Discovers Politics

Prof. Robert Schulmann
Boston University (formerly)

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Prof. Sam Schweber
Brandeis University

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Tuesday, April 12

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Chair: **Prof. Jacob Ziv**
Technion – Israel Institute of Technology

9:30 - 10:15 Einstein's Electrodynamical Pathway to Special Relativity

Prof. John D. Norton
University of Pittsburgh

10:15 - 11:00 1905 – The Miraculous Year of Unification

Prof. Hanoch Gutfreund
The Hebrew University of Jerusalem

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11:20 - 12:05 Minkowski, Relativity and Einstein's Changing Attitudes to Mathematics

Dr. Leo Corry
Tel-Aviv University

12:05 - 12:50 Post-Positivism: Einstein and A Priori Constraints on Field Theory

Prof. Thomas A. Ryckman
Stanford University

12:50 -13:20 Discussion

LUNCH

14:00 - 16:00 Session 4. Unified Theory and Gravitation

Chair: **Prof. Igal Talmi**
The Weizmann Institute of Science

14:00 - 14:45 The Notion of Spacetime: Do we Need a Further Revolution?

Prof. Sir Roger Penrose
Oxford University

14:45 -15:30 Information and Einstein's Theory of Gravitation

Prof. Jacob Bekenstein
The Hebrew University of Jerusalem

15:30 - 16:00 Discussion

16:00 - 16:20 **Coffee**

16:20 - 17:35 Session 5. Astrophysics

Chair: **Prof. Eliezer Rabinovici**
The Hebrew University of Jerusalem

16:20 - 17:05 Large-Scale Astrophysics and the Cosmological Constant

Prof. Avishai Dekel
The Hebrew University of Jerusalem

17:05 - 17:35 Discussion

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9:30 - 11:00 Session 6. The Modernity of Einstein's Ideas

Chair: **Prof. Yoseph Imry**
The Weizmann Institute of Science

9:30 - 10:15 Atoms and Photons - the Modernity of Einstein's Ideas

Prof. Claude Cohen-Tannoudji
College de France and Ecole Normale Superieure

10:15 - 11:00 The Architecture of Complexity: Bose-Einstein Condensation in Networks

Prof. Albert-Laszlo Barabasi
University of Notre Dame

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11:20 - 13:20 Session 7. Einstein and Quantum Mechanics

Chair: **Prof. Miriam Cohen**
Ben-Gurion University of the Negev

11:20 - 12:05 What is Really There, in the Quantum Domain?

Prof. Yakir Aharonov
Tel-Aviv University

12:05 - 12:50 The Einstein-Podolsky-Rosen (EPR) Argument and Quantum Mechanics - from an Embarrassment to an Asset

Prof. Itamar Pitowsky
The Hebrew University of Jerusalem

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Chair: **Prof. Dan Shechtman**
Technion – Israel Institute of Technology

14:00 - 14:45 Einstein on Space, Time, and Geometry

Prof. Michael Friedman
Stanford University

14:45 - 15:30 From "Experience and Geometry" to "Geometry and Experience"

Prof. Yemima Ben-Menahem
The Hebrew University of Jerusalem

15:30 - 16:00 Discussion

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16:20 - 17:30 Session 9. Einstein and Religion

Chair: **Prof. Moshe Deutsch**
Bar-Ilan University

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16:30 - 17:15 Einstein and Religion

Prof. Max Jammer
Bar-Ilan University

17:15 - 17:30 Discussion

17:30 Closing:

Prof. Menahem Yaari

The Israel Academy of Sciences and Humanities

Prof. Yuval Ne'eman

Tel-Aviv University

Prof. Hanoch Gutfreund

The Hebrew University of Jerusalem

ABSTRACTS

The Einsteinian Perspective

Sir Roger Penrose
Oxford University

One of Einstein's great strengths as a scientist was his ability to distinguish those physical qualities which are *subjective* from those which have an absolute significance. Thus, in his 1905 paper, introducing special relativity, he carefully analysed the subjective way that observers in different states of motion would perceive spatio-temporal relationships. Yet, as he made clear, there is, nevertheless, an objective reality out there, independent of the particular ways in which space and time would be perceived by differently moving observers. This objective picture was later formulated more clearly by Minkowski as a kind of 4-dimensional space-time geometry. Minkowski's viewpoint was later to prove essential to Einstein's *general* relativity. Here, to an even greater extent, Einstein was able to demonstrate how a clear-cut and mathematically precise picture of objective reality could be extracted from the seeming morass of irrelevance that would come from the arbitrary subjective introduction of co-ordinate descriptions by different observers.

With quantum mechanics, Einstein's striving for physical objectivity was less successful, but again one can see, from his ground-breaking 1905 papers, his deep appreciation of a need for a "reality" that might nevertheless first reveal itself in seemingly contradictory ways. Thus, Einstein was not deterred by the apparent contradiction between his perceived "finality" in Maxwell's mathematical formulation of the electromagnetic field and light, that formed the basis of his 1905 paper introducing special relativity, and the need to *replace* Maxwell's theory by a *particle*-like picture of light for his (earlier, Nobel-Prize-winning) 1905 paper on the statistical buffeting of photons with matter and on the photo-electric effect. It is striking that this seeming contradiction in Einstein's perception of electromagnetism did not deter him from using each picture in its appropriate context, in order to provide two separate ground-breaking advances in physical understanding.

Although one can but speculate as to how Einstein actually perceived light to "be", it seems clear that it was important to him to form some kind of intimacy - or even "empathy" - with this profound physical phenomenon, so that he might even imagine what it might be like to travel alongside a beam of light, or to feel at one with the random buffetings of myriads of tiny photons. Einstein had later stressed the importance to him of his abilities not only to treat physical phenomena analytically, but also to "visualize" or "feel" what those physical processes might be like. Although such perceptions, at the quantum level, might be distinctly alien, differing from our normal classical perspectives, they would not be inconsistent, or unreasonable, or without some kind of profound over-riding *reality*.

Whereas Einstein's vision of a quantum-level reality was never fully successful, it is my own opinion that he was not mistaken to *seek* such a deeper physical reality, despite the prevailing viewpoint of Bohr and others that quantum theory provides merely an operational procedure, and that one should not ask for any picture of submicroscopic activity. I would, indeed concur with Einstein that the present quantum formalism is a stopgap, and that it is fundamentally incomplete - or, even "wrong" - at a level beyond those that have been experimentally tested so far. Moreover, I contend that there are strong reasons for believing that Einstein's own general relativity will ultimately provide the route to an improved quantum theory with a more objective (though non-local) picture of physical reality. Though this is a matter for the future, the achieving of such an improved theory would represent a general confirmation of Einstein's "objectivist" perspective on physical reality.

It seems to me that this Einsteinian perspective, whereby seemingly contradictory subjective viewpoints can nevertheless reflect a deeper and more global objective truth, may also have influenced his views on politics and human affairs. Again, there could be local conflicts of viewpoint and apparently irreconcilable interpretations between antagonistic factions. Yet it would be important to understand how these individual factions might be regarding the whole from a limited and subjective viewpoint. Compassion and understanding are indeed vital ingredients in the resolution of conflicts throughout the world.

The View Behind The Kelvin Clouds

Yuval Ne'eman
Tel-Aviv University

In his April 1900 Brighton address, Lord Kelvin pointed to two "dark clouds" partly obscuring the view (the aether drift experiment and failure of equipartition) marring the panoramic beauty of the two successful unifications – the crowning achievements of XIXth century physics, namely deriving the physics of Heat as an application of Mechanics – and the physics of Light from Electromagnetism.

Kelvin very perceptively estimated it might take about a hundred years and a conceptual revolution to overcome that darkness. I shall report on the present state of this program. The clearing of the clouds involved the construction of two new fundamental physical theories, namely *Relativity* and *Quantum* Mechanics, with marked non-intuitive features very important at some characteristic scale (large for Relativity, small for Quantum Mechanics) and much weaker at our own "classical" scale (small v/c, decoherence).

The general Theory of Relativity, Einstein's great achievement at the relativity end, has provided a contribution to Kelvin's panoramic scenery, namely the merger between *mechanics* and *Gravity* (the latter a basic *interaction*, like electromagnetism). Completion of the program also requires tackling the two clouds' overlap, namely,

(1) Quantum Gravity where both theory and experiment are presently involved in the selection between two competing candidates, *String* (or M) *Theory* and *Loop Gravity*, aside from verifying two suggestions relating to possible overlaps between the non-intuitive features at their extremes, namely the merger of infinite multiverse cosmologies and QM *Many-Worlds* interpretation, and (2) use of *noncommutative geometry*.

Meanwhile, a new cloud has appeared, with the finding that the universal expansion is in an accelerating phase fitting Relativity but raising new questions as to the repulsive force and its "*quintessence*" sources.

So much for the clouds. As to further (panoramic) unification, the program first doubled when Einstein's unsuccessful work on merging the two interactions known in 1900 had to be replaced in the thirties by a search for a four-interactions merger. The Electromagnetic and Weak Nuclear forces were unified by Weinberg and Salam, while we (YN, H Goldberg, M Gell-Mann, G Zweig) have classified hardron matter and understood its structure. This enabled G. t' Hooft, D. Gross, H. Politzer and F. Wilczek to construct Quantum Chromodynamics, the Strong Nuclear Force.

Further Unification will have to relate the present three blocks (Gravity, the Electroweak and QCD), explain "hierarchy" and the generations structure. Will that occupy us for the next hundred years?

Einstein and the Quest for a Unified Theory

David Gross
University of California, Santa Barbara

Einstein spent the last thirty years of his life searching for a unified field theory. In this talk I shall discuss Einstein's attempts at unification. I shall look at his mistakes, ask why he went wrong, and wonder what might have happened if he had followed a slightly different route. I shall then discuss, very briefly, where we stand today in realizing Einstein’s goals.

The Emergence of the Einstein Phenomenon: Reconciling Science, Politics, and Personal Identity after World War I

Diana Kormos Buchwald
California Institute of Technology

What have we learned and what is there still to learn about Einstein, in his own words and those of others? The Einstein Papers Project has published, in a detailed, comprehensive form Einstein's scientific manuscripts, his notebooks, lectures, popular articles, as well as his private and professional correspondence through 1921, when Einstein was 42 years old. In the fall of 1919, Einstein emerged as a celebrity scientist, his image instantly recognizable worldwide. After World War I, his involvement in political, humanitarian, and educational issues and the clamor he generated shape his public persona. He emerged as an engaged scientist and continued on this trajectory to the end of his life. The talk will offer reflections on Einstein’s relationship to historical events, the war, German and Allied politics, and how, in the middle of hunger and deprivation, as well as the demands of the press, teaching, and personal obligations, he managed to continue scientific work on many important topics. We shall examine what has been accomplished so far in documenting Einstein's life and work, some of the challenges for future Einstein scholarship, and what his scientific and humanitarian legacy means today.

Einstein and Relativity in the Context of Weimar Germany

David Rowe
Johannes Gutenberg University, Mainz

Einstein was famous for being indifferent to his own worldly fame. Nevertheless, he was deeply interested in the psychological roots of the relativity revolution. Sometime during the 1940s he wrote that:

> *For me it was always incomprehensible why the theory of relativity, whose concepts and problems are so far removed from practical life, should have found such a lively, even passionate resonance in the widest circles of the population for such a long time. Since the time of Galileo nothing quite like that has happened. Yet then the church's officially sanctioned view of man's place in the cosmos was shaken - an event of patent significance for cultural and political history - whereas the theory of relativity is concerned with the attempt to refine physical concepts and to develop a logically complete system of hypotheses for physics. How could this have occasioned such a gigantic and long-lasting psychological reaction?*

This suggests that, on the one hand, Einstein found the parallels between "his" scientific revolution and the one linked with the names of Copernicus and Galileo far-fetched. On the other hand, he was convinced that the reception of relativity in Germany after 1919 was deeply influenced by political factors.

For decades Weimar culture has been the object of probing historical studies, many of which have focused almost exclusively on persons and events located in Berlin, where Einstein resided from 1914 to 1933. Yet while his name often comes up in such works, he is usually portrayed in them as a figure far removed from the era's center stage. The relativity revolution - most cultural historians seem to imply—was merely a passing fad, one that attracted far less interest than Josephine Baker dancing in her banana skirts. Still, such a conclusion appears rather odd in the face of what everyone knows about Einstein's biography, namely, that he quickly moved into the stratosphere of stardom after November 1919.

Berlin was then in a state of chaos. The immediate post-war era was one of the most tumultuous periods in German history, as was the period of the early 1930s when the Weimar Republic entered its death throes. It should therefore come as no surprise that Einstein was decidedly active during both. He sought to restore relations between intellectuals in former enemy camps; at the same time he tried to build alliances against encroaching fascist and militarist tendencies in Europe. Indeed, a close examination of his political activities, both in Berlin and while traveling abroad, reveals how keenly attuned he was to the problems of the period. Quite apart from his fame as a scientist, Einstein was not only an astute observer of the political scene, he was a moving force within it whose words and deeds were closely followed by the German Foreign Ministry. Little wonder that professional diplomats deemed him a major asset for the Weimar Republic.

While German embassies around the world reported on his impact abroad, the German press took an active part in enlivening the debates and controversies surrounding Einstein's theory of relativity (or at least what they took that theory to be). Einstein's name and photogenic face eventually made their way around the world, but nowhere was his celebrity so established and exploited as in the German capital. In Berlin public fascination with Einstein and his theory went hand in hand with other cultural currents that swept the Weimar landscape. There the media giant Ullstein set the pace for fast- and trend-breaking journalism, above all through their firm's widely read "Berliner Illustrirte Zeitung," which ran feature stories on the "New Copernicus" and his exploits on numerous occasions. Through such channels the personality cult surrounding Einstein and his sensational theory quickly seeped into the daily discourse of the city's inhabitants. The results were at times funny, occasionally ridiculous, and often polarizing, like so many other phenomena of Weimar culture. To the extent that the relativity revolution reflected a new sensibility with deep psychological roots it could not have found more fertile soil than Einstein's Berlin.

Einstein Recovers Judaism and Discovers Politics

Robert Schulmann
Boston University (formerly)

Universally recognized as a physicist of the first rank, Albert Einstein as a political figure is far more difficult to assess. He never engaged systematically in the activities of any political party and remained throughout his life above any political infighting. The idiosyncratic cast of his political thinking further complicates the issue. And yet for many there is almost a mystical identification of his person and name with integrity in the political sphere. The key to understanding this identification lies in recognizing its moral roots, a fact which explains both the powerful hold on the public his political pronouncements continue to exert to this day and the source of the myth of Einstein's naiveté in politics. Idealistic views unchecked by a realistic assessment of the everyday world to which they must apply may fairly be called naïve. This charge does not apply to Einstein. The same muscular pragmatism which marked the early stages of his personal and professional life came to shape his political views, once these emerged after World War I, above all a willingness to evaluate ideas with respect to their consequences in everyday life. Unlike a professional politician, however, he was not accountable to any constituency other than himself. Drawing on his international fame as the second Newton, he enjoyed the luxury of reflecting on politics and directing his energies to social ends without making the usual political compromises. Events were to alter his views but never to force concessions of principle.

Einstein's political interests only crystallized in 1919 after his most startling discoveries in physics lay behind him. In the critical years leading up to his greatest scientific achievements his political and social interests lay fallow, their moral roots unarticulated. Arriving at a considered opinion on an array of public questions was not a simple matter. This paper argues that it was his search for Jewish identity in the years following the Great War, as well as his growing commitment to Zionism, that laid the foundation for his active political engagement. The growing hostility toward Jews in German society was the all-important catalyst. In characterizing this swelling tide of anti-Semitism, he revealed a particular sensitivity to its psychological component: "I see how schools, the satirical press, and countless other cultural institutions of the non-Jewish majority undermined the confidence of even the best of my fellow-Jews and felt that it should not be allowed to continue in this fashion." Anti-Semitism harbored another, even uglier lie, one that provoked moral revulsion in Einstein. Gentile contempt for the Jew was one thing, but even more despicable he found the scorn which his fellow-German Jews heaped on their Russian and Polish brethren, the *Ostjuden*. Various measures contemplated by the Prussian government to control and even deport East European Jews after the war exacerbated the fear of many German Jews that they were the real targets of official displeasure. Einstein dismissed this fear with the acerbic observation that it was "a Jewish weakness . . . always and anxiously try to keep the Gentiles in good humor." Jewish anti-Semitism, he thought, represented nothing less than a degrading ritual of redirecting onto the most vulnerable members of the community the Gentile anti-Semitism intended for all Jews. "Let us leave anti-Semitism to the Aryan and save love for our own kind."

Einstein and Nuclear Weapons

Sam Schweber
Brandeis University

On Wednesday, July 12, 1939, early in the morning, Eugene Wigner picked up Leo Szilard at the King's Crown Hotel, located next to Columbia University in Manhattan, to drive to Peconic, Long Island, to see Einstein who was spending his summer vacation there in the house of a friend of his. Both Wigner and Szilard were outstanding physicists who had emigrated to the United States because of the rise of Nazism in Germany. Wigner was the Thomas D. Jones Professor of Mathematical Physics at Princeton University, and Szilard was a research fellow at Columbia working with Fermi to establish all the experimental facts concerning the fissioning of U238 and U235, by slow and fast neutrons. The discovery of the fission of uranium by slow neutrons, by Hahn and Stassman in l938, and the tentative explanation of the phenomena that had been advanced by Frisch and Meitner had electrified the nuclear physics community. American nuclear physicists had first heard of it when Niels Bohr had lectured on it on his arrival to the United States in January 1939. Szilard immediately saw the possibility of producing a chain reaction should the fission process result in the production of neutrons. Whether the chain reaction could be controlled or would produce an explosion depended on the energy of the produced neutrons and the probability of the two uranium isotopes that make up natural uranium to capture a neutron and fission, as well as on the concentration and geometrical arrangement of the uranium isotopes. In either case, the amount of energy released per fission was orders of magnitude greater than in a chemical reaction. Given the likelihood of war breaking out soon and Nazi Germany working on the production of nuclear weapons and cutting off the supply of uranium ores from Czechoslovakia and from the Belgian Congo, it was important to insure the availability to the United States of the raw materials for their own researches on the processes. Wigner and Szilard, who had known Einstein since the time they were university students in Berlin in the early 1920s, initially had thought of enlisting his help to intervene with the Queen of Belgium, who was a personal friend of Einstein. However the eminent mathematician Oswald Veblen, a colleague of Wigner's in Princeton, had convinced Wigner that the US government ought to be informed of the developments and of the possibilities of nuclear weaponry and of controlled nuclear reactors for the propulsion of ship and submarine. Thus Wigner and Szilard were going to enlist Einstein's help in alerting President Roosevelt of the dramatic gains – military and economic – should the fission process be mastered and designed to yield the desired ends; and of the danger that Nazi Germany might develop nuclear weapons first. The Peconic meeting eventually resulted in the famous letter of August 12, 1939 from Einstein to Roosevelt that was delivered to Roosevelt by Alexander Sachs in October 1939.

Based on the Sachs correspondence in the Einstein Archives, I will detail the considerable involvement of Einstein in the bomb project until mid June 1940, when the Briggs Committee, that had overseen the atomic energy program, was placed under the aegis of the Vannevar Bush's National Defense Research Committee (NDRC).

In retrospect, as important and impressive as had been the activities of Einstein, Sachs, Szilard, Teller and Wigner, effectively, the bomb program in the United States started upon the receipt of the British MAUD report conclusions in September 1941, which detailed the Frisch-Peierls calculations regarding the critical mass of U235 needed for a uranium bomb and their estimation of the feasibility of separating the U235 isotope from “natural” uranium. It is only after studying this document that James Conant, who was in charge of the NDRC atomic energy program, became convinced that an atomic bomb could be produced in time to alter the course of the war. Thereafter, a recommendation to go ahead with the project, to build a bomb, was made by Bush to Roosevelt in mid October 1941, a few weeks before Pearl harbor. The timing was crucial. It would not have been possible to obtain the top priority ranking for the project after Pearl Harbor.

After June 1940 Einstein was not involved in any of the further developments regarding atomic energy and atomic bombs. His reaction to the uses of atomic bombs and his subsequent efforts to ban nuclear armament and his relentless focus on the need for a supranational government will be detailed and compared with the positions taken by Bohr, by Oppenheimer and by Hans Bethe, the latter a member with Einstein of the Emergency Committee of Atomic Scientists. The connection between Einstein's stand on nuclear weapons and on civil liberties during the McCarthy era will be stressed.

There is perhaps no better way to indicate how importantly and seriously Einstein took the issue of nuclear weaponry and how deeply he believed in the necessity of disarmament than to point out that one of his last acts was to sign the Russell-Einstein manifesto that led to the Pugwash meetings; and the last thing he wrote as he lay in his hospital bed knowing that the end was at hand was the following:

"In essence, the conflict that exists today is no more than an old-style struggle for power, once again presented to mankind in semi-religious trappings.
The difference is that, this time, the development of atomic power has imbued the struggle with a ghostly character; for both parties know and admit that, should the quarrel deteriorate into actual war, mankind is doomed. Despite this knowledge, tatesmen in responsible positions on both sides continue to employ the well-known technique of seeking to intimidate and demoralize the opponent by marshaling uperior military strength. They do so even though such a policy entails the risk of war and doom. Not one statesman in a position of responsibility has dared to pursue the only course that holds out any promise of peace, the course of supranational security, since for a statesman to follow such a course would be tantamount to political suicide. Political passions, once they have been fanned into flame, exact their victims ....."

Einstein's Electrodynamical Pathway to Special Relativity

John D. Norton
University of Pittsburgh

Einstein later recalled that he spent seven or more years on the work that led to his special theory of relativity. It was only in the last five or six weeks that Einstein turned to non-Newtonian notions of space and time. For the bulk of the time, Einstein grappled with problems in electrodynamics within a Newtonian context and failed to solve them. Since the documentary source materials are so scant, we know only a little of these efforts. The magnet and conductor thought experiment led Einstein to consider transformations that mixed the electric and magnetic fields in his quest to realize the principle of relativity; and he considered an emission theory of light in which the velocity of the emitter is added to the velocity of light emitted. I suggest that one particular emission theory of light both conforms well to Einstein's later remarks that his explorations were similar to those of Ritz; and it also looks like a promising solution to the problems Einstein faced in accommodating various field transformation laws to then current electrodynamic theory. Nonetheless the theory failed and Einstein came to be convinced that all emission theories must fail. While Einstein's famous chasing a light beam thought experiment proves to be ineffective as a criticism of ether based theories of electrodynamics, I will argue that it provides an especially effective way to see that all emission theories fail and I conjecture that this is why the thought experiment was given pride of place in Einstein's autobiographical reflections.

1905 – The Miraculous Year of Generalization and Unification

Hanoch Gutfreund
The Hebrew University of Jerusalem

Einstein, in his own words, was: "driven by the need to generalize" and by "the wonderful feeling to recognize the unity of complex appearances, which to direct sense experiences, appear to be quite separate things." The 1905 papers can be viewed as a result of that need to generalize and as a consequence of the recognition of unity of apparently separate things. They deal with concepts and phenomena at the interfaces between the three domains of classical physics – mechanics, thermodynamics and electrodynamics. Describing two of them simply as explaining certain experiments (the photoelectric effect) or phenomena (the Brownian motion) is misinterpreting their significance and underestimating their importance. In the lecture I intend to discuss these papers in the context of their goals and motivation, and their contribution to a more unified picture of classical physics.

Minkowski, Relativity and Einstein's Changing Attitudes to Mathematics

Leo Corry
Tel-Aviv University

Two years after Einstein’s relativity paper of 1905, Hermann Minkowski undertook the reformulation of the new theory in mathematical terms that were to become its standard language, and that allowed its further development. Einstein’s initial attitude towards Minkowski’s approach was rather unsympathetic, and it reflected a more general attitude of him towards mathematics and its role in physics. Still, it was not long before Einstein realized that this formulation was essential to his attempts to generalize the theory so as to cover gravitation and arbitrarily accelerated systems of reference.

Minkowski was a prominent mathematician, known mainly for his contributions to number theory. He had arrived in Göttingen in 1902, where he reunited with David Hilbert, an old fellow student from his Königsberg days, and now one of the world-leading mathematicians. Their renewed collaboration contemplated a very broad study of current research in many fields of mathematics as well as of physics, and a program for further developing Göttingen into a world-class institution for the exacts sciences, and into a hotbed of scientific ideas that would continue to attract gifted students from all over the world.

Minkowski came to the study of Einstein’s early papers on relativity as part of this very ambitious and far-reaching program. In the years immediately preceding his own contributions, Minkowski studied in detail, in collaboration with Hilbert and other Göttingen colleagues and students, many of the most important, recent works on electrodynamics and the theory of the electron, including those of Lorentz, Poincaré, Schwarzschild and Abraham.

This lecture will survey the general background to Minkowski’s incursion into relativity, of which Einstein’s work represented just one side, and in which the rich and complex interaction between mathematics and physics in Göttingen since the turn of the twentieth century played a decisive role. At the same time, it will illuminate the changing relations of Einstein to mathematics, in the wake of Minkowski’s work, and his willingness to attribute increasing significance to mathematical formalism in developing physical theories.

Post-Positivism: Einstein and *A Priori* Constraints on Field Theory

Thomas A. Ryckman
Stanford University

Einstein explicitly recognized the positivist influences of Hume and Mach in arriving at the revolutionary ideas of the special theory of relativity, in particular, a non-absolute relation of simultaneity between distant events. In other contexts, non-positivist philosophers or philosophically minded scientists were frequently mentioned; of these, Spinoza and Poincaré were accorded special respect. His references to Kant and to any Kantian approach to epistemological issues in physics were nearly always cautious, if not severely critical. The exception is one intriguing remark in the latter part of his life made in his "Replies to Criticisms":

> *I did not grow up in the Kantian tradition, but came to understand the truly valuable which is to be found in his doctrine, alongside of errors that today are quite obvious, quite late. It is contained in the sentence: "The real is not given (gegeben) to us, but rather "set as a task" ("aufgegeben"). (1949, 680)*

It may be recalled that Kant's distinction *gegeben/aufgegeben* is found not in the Transcendental Analytic, but in the Transcendental Dialectic, where the emphasis is not on *constitutive principles* but on the *regulative* use of principles of pure reason. In particular, it occurs in the celebrated section on the Antinomies of Pure Reason, whose overall aim is the recognition that the antinomies stem from the assumptions of a *dogmatic transcendental realism* treating appearances as things-in-themselves, while they are averted and dissolved through the *therapeutic function of transcendental idealism*. In fact, while Einstein was yet a young man, leading exponents of both major schools of Neo-Kantianism (the "Southwest" and "Marburg" schools) concisely formulated the essence of transcendental idealism through the contrast *gegeben/aufgegeben.*

It is therefore instructive to attempt to see what meaning the contrast held for Einstein, a self-described "opportunist" in epistemology, borrowing freely from different philosophical traditions as need arose. I shall argue that the requirement of general covariance, described by Einstein as a "heuristic principle", plays the role of a regulative ideal enjoining that any reasonable field dynamics must be formulated without the supposition of a background of bare spacetime points to which field functions attach as properties. Its intent is to eliminate not only the background metric but also the bare manifold itself as an absolute arena for dynamical laws so that reference to spacetime is reference to the frame of the dynamical field itself. In accord with the Marburg school of Neo-Kantianism but in opposition to Kantian doctrine itself, Einstein's regulative use of this ideal of pure reason has also a constitutive significance for the field-theoretic concept of a physical object, and so of a particle, as shall be seen by considering the Einstein requirement of "separability" in the light of this regulative ideal governing field theory. I will conclude with an examination of several of Einstein's more noteworthy expressions that seem to avow a Platonist or Pythagorean conception of the role of mathematics as an instrument of discovery in physics, suggesting that these are better understood from the therapeutic perspective of transcendental idealism.

The Notion of Spacetime: Do we Need a Further Revolution?

Sir Roger Penrose
Oxford University

Though he was one of the first to perceive the quantum nature of matter, Einstein was never happy with the way that quantum theory later developed. Whereas its lack of determinism is often blamed for Einstein's unease with that theory, it would appear that he may have been even more disturbed by the seemingly *subjective* picture of reality that the conventional “Copenhagen interpretation” of quantum theory gave rise to, according to which the quantum state-vector represents merely the observer’s “knowledge” of a physical system, rather than describing some underlying quantum reality.

Einstein's own subsequent attempts at finding inner inconsistencies with the quantum formalism led to what came to be known as “EPR (Einstein – Podolsky - Rosen) effects” which, when combined with the subsequent theoretical work of Bell, showed the incompatibility of the expectations of quantum mechanics with any *local* objectively realistic picture of the physical world. Many subsequent experiments have now convincingly confirmed the quantum expectations, leading to a clear implication that any objective picture of quantum reality would have to incorporate severely non-local (or acausal) ingredients.

No doubt this firm conclusion would have shocked Einstein, but my guess is that given the choice, he would have preferred non-locality (or even acausality) to a lack of physical objectivity. Einstein was not averse to changing his mind; we have, after all, a precedent in Einstein’s initial unhappiness with Minkowski’s four-dimensional space-time formalism for special relativity, while he later became converted to the idea, making brilliant use of it in his own discovery of *general* relativity. Can “quantum non-locality” be likewise developed into some novel picture of an objective physical reality going beyond Minkowski’s vision, to provide a geometrical description of reality that is fundamentally non-local? A further clue is to be found in the phenomenon of “quantum teleportation”, according to which the “quantum information” in a quantum state appears to have to be propagated acausally - and even “backwards in time” under certain circumstances. I have coined the term “quanglement” for this quantum notion (so as to remove the inappropriate association with an “information” that would have to be causally propagated). These considerations suggest that some form of non-local quantum geometry may well be required to replace the normal notion of spacetime.

The theory of spin networks that I introduced in the late 1950s (and which is currently incorporated into the loop-variable approach to quantum gravity) is basically a primitive theory of quanglement. This may be regarded as a precursor of *twistor theory* (which is presently enjoying a renaissance in high-energy physics). Twistors provide an approach to a non-local geometry where, in effect, helicity-carrying light rays provide the basic ingredients (and seem to be carriers of quanglement), these taking the place of the “events” of the normal space-time descriptions. The physical appropriateness of twistor theory as providing a non-local alternative to classical space-time geometry will be explored in this talk.

Information and Einstein’s Theory of Gravitation

Jacob D. Bekenstein
The Hebrew University of Jerusalem

The language of information has become commonplace in the last decade in discussions of central issues in Einstein's gravitational theory. We thus hear of the information paradox of black holes and the holographic principle. Less well known are the consequences of gravitation theory for physically embodied information. These concern questions such as "how much information can ultimately fit on the head of a pin ?" and "can the visible universe be described in a subsystem of itself ?" Here I examine the foundations of the subject of entropy bounds, of which the holographic bound is just one example. Entropy bounds offer an easy road towards understanding the ultimate natural limits on information storage. They are best conceived as consequences of the generalized second law of thermodynamics for hybrid matter-black hole systems. Accordingly, after a brief self-contained introduction to the connection between thermodynamics and information, and to black hole thermodynamics, I review the examples and theoretical arguments for the validity of the generalized law, including the role of Einstein's equivalence principle. The arguments based on the generalized second law for the holographic entropy bound are then analyzed. Since the holographic bound is efficient only for universe-size systems, I shift attention to the universal entropy bound, giving two separate arguments for it, one employing Einstein's gravitational redshift together with the generalized second law, and one designed to avoid complications stemming from quantum buoyancy, itself a consequence of the equivalence principle. I conclude with a discussion of Bousso's covariant entropy bound in its role of the archetypal entropy bound, and of the chances that yet more efficient entropy bounds may come to light.

The Accelerating Universe and Einstein's Cosmological Constant

Avishai Dekel
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The last decade has led to a revolution in our physical understanding of the Universe we live in, which makes a direct connection to Einstein's General Relativity of almost a century ago. This revolution has been driven by exciting new observations from space and from big telescopes on earth in different wavelengths. We learned first that most of the mass in the universe is in the form of an unseen "dark matter" of a yet unknown nature. More recent observations told us that the Hubble expansion of the Universe is accelerating, and that space-time is of nearly flat curvature. These imply that the mean energy density in the Universe is actually dominated by an even more mysterious component, loosely termed "dark energy". We associate this phenomenon with the cosmological constant - an intrinsic term in Einstein's equations of General relativity, responsible for a repulsion by the vacuum as opposed to the common gravitational attraction by masses. Several variants of the theory are being addressed by current and future cosmological observations. Our challenge is to uncover the exact nature of the dark-matter and dark-energy phenomena, and to understand the origin for the specific content and structure of the Universe as observed.

Atoms and Photons The Modernity of Einstein's Ideas

Claude Cohen-Tannoudji
Collège de France and Ecole Normale Supérieure

Einstein was the first physicist to introduce the idea that the radiation field is quantized and consists of quanta, called now photons, having an energy hν and a linear momentum hν / c. He extended also the new statistics introduced by Bose for a gas of photons to a perfect gas of atoms, predicting in this way a new spectacular phenomenon, Bose-Einstein condensation.

I will review in this presentation a few modern extensions of these ideas. First, multiphoton ionization, where an atom is ionized, not by the absorption of a single photon, as in the first description of the photoelectric effect given by Einstein in 1905, but by the absorption of several photons. I will then show how resonant exchanges of linear momentum between atoms and photons can give rise to huge radiative forces exerted by laser beams on atoms, allowing one to cool these atoms to extremely low temperatures. One of the most spectacular applications of the ultracold atoms obtained by these methods is the observation of Bose-Einstein condensation in ultracold atomic gases. New fascinating perspectives opened by these gaseous condensates will be briefly discussed.

The Architecture of Complexity: Bose-Einstein Condensation in Complex Networks

Albert-László Barabási
University of Notre Dame

Networks are everywhere. The brain is a network of nerve cells connected by axons, and cells themselves are networks of molecules connected by biochemical reactions. Societies, too, are networks of people linked by friendship, familial relationships, and professional ties. And networks pervade technology: the Internet, power grids, and transportation systems are but a few examples. Yet despite the importance and pervasiveness of networks, scientists have had little understanding of their structure and properties. How do the interactions of several malfunctioning nodes in a complex genetic network result in cancer? How does diffusion occur so rapidly through certain social and communications systems, leading to epidemics of diseases and computer viruses? How do some networks continue to function even after the vast majority of their nodes have failed?

Over the past few years, scientists from a variety of fields have discovered that complex networks seem to have an underlying architecture that is guided by universal principles. We have found, for instance, that many networks - from the World Wide Web to the cell's metabolic system to the actors in Hollywood - are dominated by a relatively small number of nodes that are highly connected to other sites. These important nodes, called "hubs," can greatly affect the overall behavior of a network, for instance, making it remarkably robust against accidental failures but extremely vulnerable to coordinated attacks.

The rate at which nodes acquire links in a network depends on their fitness to compete for links. For example, in social networks some individuals acquire more social links than others, or on the www some webpages attract considerably more links than others. We find that this competition for links allows fitter nodes to overcome the more connected but less fit ones. I will show that despite their irreversible and nonequilibrium nature, networks follow Bose statistics and can undergo Bose-Einstein condensation. Addressing the dynamical properties of these nonequilibrium systems within the framework of equilibrium quantum gases predicts that the "first-mover-advantage", "fit-get-rich," and "winner-takes-all" phenomena observed in competitive systems are thermodynamically distinct phases of the underlying evolving networks.

What is Really There, in the Quantum Domain?

Yakir Aharonov
Tel-Aviv University

Contrary to accepted wisdom we show that it is possible to test all the predictions of Quantum Mechanics without disturbing the observed Quantum System. This is achieved by a new type of measurement that we named Weak Measurement. The result of such measurements are weak values. Weak values are more fundamental than eigen values which are special cases of them. With the aid of such measurements we reveal a host of new phenomena in the Quantum domain. I will discuss some of those new phenomena, many of which are now under observation in Laboratories around the world. I will also show that this approach provides a new solution to the outstanding problem of the so called "collapse of the wave function".

The Einstein-Podolsky-Rosen (EPR) Argument and Quantum Mechanics - from an Embarrassment to an Asset

Itamar Pitowsky
The Hebrew University of Jerusalem

In 1935 Einstein, Podolsky and Rosen (EPR) published a paper whose explicit purpose was to criticize the accepted wisdom about quantum mechanics. They argued that in some circumstances it is possible to associate simultaneous values with the position and the momentum of a single particle. The strength of the EPR argument rests on the simplicity of their assumptions: Firstly, the universally accepted principle of relativity that originated with Einstein's 1905 paper; secondly, the assumption which they called *a criterion of reality* and is grounded in common sense. The argument has been greatly improved in the 1950's by David Bohm who, by using spin values rather than position and momentum, brought the EPR proposal closer to experimental realization.

The EPR argument seems convincing, and the authors distinguished enough to expect some intensive debate to arise. Although some contemporary physicists replied, most notably Bohr (whose reply is hard to follow, and its meaning still debated today) the challenge was not really met. In particular, no *quantitative* analysis of the EPR assumptions was attempted. It looks as if most physicists ignored the issue, or simply assumed that Bohr had taken care of it. Only in the 1960's, almost thirty years after the paper, J. S. Bell demonstrated that the EPR assumptions lead to a conflict with the predictions of quantum mechanics. Since then experiments confirmed the latter, as opposed to the "local realism" assumed by EPR.

In the lecture I shall present a particularly simple version of the Einstein-Podolsky-Rosen argument and Bell's rebuttal, which demonstrates clearly the conflict between the principles of special relativity and the criterion of reality. The EPR argument builds on the property of some multi-particle quantum states which is nowadays called *entanglement*. What appeared to Einstein and his collaborators as a possible source of trouble for quantum theory turned out, following Bell's work, to be an asset. I shall review a few "miraculous" communication and computation protocols that can be executed -at least in theory- with the aid of entanglement.

Einstein on Space, Time, and Geometry

Michael Friedman
Stanford University

Einstein's general theory of relativity takes the revolutionary step of applying a non-Euclidean geometry to the physical world for the very first time. This has had enormous impact on philosophy in the twentieth century, and Einstein himself published a celebrated paper on the philosophy of geometry, "Geometry and Experience," in 1921. I discuss the very surprising way in which Einstein was thereby able to combine two hitherto unconnected issues in the philosophy of space and time: the relativity of space, time, and motion on the one side and the question of the geometry of physical space on the other. Understanding how these two issues unexpectedly combine is indispensable for grasping the true philosophical significance of Einstein's work.

The logical empiricists, in particular, took Einstein's "Geometry and Experience," as a model for their own philosophy of geometry. Rejecting Kant's conception of the necessary and synthetic a priori character of Euclidean geometry, as an a priori form of our spatial intuition, they developed a sharp distinction between pure and applied, mathematical and physical geometry, according to which pure or mathematical geometry is an uninterpreted formal system having no intrinsic relation to spatial intuition or any other type of perceptual experience. Such an abstract formal system then has to be related to actual physical experience by "coordinating definitions" in order to become applied or physical geometry. Most importantly, however, there is always an element of arbitrariness or stipulation in choosing one such set of coordinating definitions over another, and, in this way, the logical empiricists saw an intimate connection between their philosophy of geometry, Einstein's work, and the conventionalism of Henri Poincaré.

Yet, when we examine the text of "Geometry and Experience" itself, we see that Einstein presents Poincaré's geometrical conventionalism as the only real *alternative* to the conception he is now trying to articulate, and Einstein claims, in a striking passage, that he had to *reject* Poincaré's conventionalism in order to formulate the general theory of relativity. So we now have a serious historical and philosophical puzzle. How could the logical empiricists have so badly misinterpreted Einstein's paper (apparently with some encouragement from Einstein himself)? What is the real relationship between the general theory of relativity, "Geometry and Experience," and Poincaré's philosophy of geometry? Answering these questions involves locating Einstein's paper against the background of the late nineteenth-century debate on the foundations of geometry between Poincaré and Hermann von Helmholtz, and it leads us, in the end, to a deeper appreciation of how the foundations of geometry and the traditional problem of the relativity of motion unexpectedly combine in Einstein's work.

From “Experience and Geometry” to “Geometry and Experience”

Yemima Ben-Menahem
The Hebrew University of Jerusalem

Einstein’s “Geometry and Experience” is a response to Poincaré’s “Experience and Geometry”. At issue is the status of geometry in light of the theory of relativity. The received view, originating with Einstein, is that the general theory of relativity, by vindicating an empirical conception of geometry, undermines geometric conventionalism. To challenge the received view, one must show that there are interpretations of the general theory of relativity that are empirically equivalent to the standard interpretation, but do not invoke the dynamical spacetime that, in Einstein’s view, is the thrust of his theory. Beginning with an outline of how the question of interpretation arises in the context of the general theory of relativity, this presentation examines the rationales underlying a number of such non-standard interpretations, and the counter arguments made by proponents of the standard interpretation. In light of this examination, I argue, talk of the death of geometric conventionalism appears to be somewhat premature.

The implications of the theory of relativity do not appear to be favorable to the conventionalist. In the equations of the general theory of relativity (GR), the mathematical entities representing geometrical features of spacetime are determined by the mathematical entities representing the distribution of masses and fields. Integrated into the network of physical laws, geometrical properties appear to be as empirical and non-conventional as any other physical magnitude. There is thus a clear sense in which, in GR, conventionalism as to geometry has been overtaken by empiricism. This was certainly Einstein’s view of the matter. Yet notwithstanding the fact that the authors of many of the philosophical works, written after the theory was first disseminated, were clearly in awe of the new theory and its creator, and sought to convey its philosophical meaning to a wider audience, these works trumpet a conventionalist message quite at odds with Einstein’s actual position. Contemporary philosophers, on the other hand, typically engage in a critique of these earlier interpretations, and espouse an empiricist, anti-conventionalist stance on geometry more in harmony with Einstein’s.

Turning from the philosophers to the physicists, however, we will see that over the years alternative approaches to GR have emerged. On some of these approaches, we are not forced to accept the dynamic curved spacetime that Einstein took to be the thrust of GR. To the extent that such non-standard interpretations of GR stand up to scrutiny, GR entails neither the vindication of geometric empiricism, nor the refutation of geometric conventionalism. Ignoring these alternatives, as some philosophers do, can lead to serious confusion. The problem running through much of the literature is the following: Both sides to the debate over conventionalism tend to assume a particular interpretation of the theory - say, Einstein’s (or Einstein’s at a particular time) - and proceed from there, with the conventionalists asserting, and their opponents denying, that GR gives us the freedom to choose a metric as we see fit. But this is an ill-conceived debate: once a particular interpretation is endorsed, there is no significant freedom with regard to choice of a metric. In this sense, the conventionalist exaggerates our discretion. On the other hand, as long as we fail to take seriously the interpretive latitude we do enjoy, the anti-conventionalist argument falls short: no matter how little freedom we have, according to GR, to stipulate the values of the mathematical entities appearing in its equations (or the nature of their interrelations), questions regarding the *interpretation* of these entities may still remain open. Certainly, it is impossible to have it both ways: to uphold both Einstein's geometric interpretation of GR and the conventionality of geometry. At the same time, conventionalism cannot be said to have been refuted unless the alternative interpretations of GR can be demonstrated to be implausible. After taking a look at some of these interpretations, I will argue that conventionalism has actually reemerged as a viable philosophical position.

Although I maintain that the conventionality of geometry is not refuted by GR, I do think it necessary to draw attention to two methodological points conventionalists usually overlook.

First, the distinction between theory and interpretation is unstable over time, and may be hard to draw even at a given moment, hence it may be impossible to reach a definitive verdict on whether a particular alternative challenges the theory or 'just' its interpretation. Ultimately, rival interpretations of the kind considered in this presentation are the driving force behind rival research programs, and have the potential to evolve into competing theories. The prospect of such divergence should deter us from drawing conclusions about equivalence and under-determination prematurely; such conclusions are by their very nature tentative, pending further developments in physics.

Second, as both GR and the special theory of relativity originated in insights about equivalence, an element of conventionality might seem to be built right into the theory. It is important to recognize, however, that Einstein's use of equivalence arguments differs fundamentally from that of the conventionalist. Whereas conventionalists employ equivalence in the service of skeptical no-fact-of-the-matter arguments, Einstein showed that equivalence arguments have *empirical import*. From the methodological point of view, a valuable lesson to be learned from the theory of relativity is the importance of attending to the role of equivalence arguments in science.

Einstein and Religion

Max Jammer
Bar-Ilan University

It is rarely known, and generally ignored even by Einstein's biographers, that next to physics the philosophy of religion and the quest for spiritual truth preoccupied Albert Einstein, in fact so much that it has been said "one might suspect he was a disguised theologian." Of course, Einstein's fame rests first of all on his monumental contributions to the development of modern physics, as the present symposium clearly shows. However, even beyond the world of physics, Einstein's ideas about religion, questions of whether he was an atheist, whether he was a mystic, or whether he believed in God, and if so what kind of God - all these questions command our attention, simply if only by virtue of the powerful mind that dealt with them.

But as far as these questions have been discussed at all, their answers have been distorted both by atheists and by religious authors, each eager to claim Einstein as one of their own.

The purpose of this talk is to present Einstein's ideas about religion *sine ira et studio*, that is, as objectively as possible.

Our case-study begins with a discussion of Einstein's religious education and his early piety which urged him even to reprehend his parents for not observing the Jewish dietary laws. It then describes the reasons of Einstein's sudden and drastic conversion into a fanatic freethinker just at the time when he should have prepared himself for his bar mitzvah. His fervid rejection of anthropomorphic conceptions of God continued throughout his life even when, as a technical expert at the Patent Office in Bern, he became deeply religious, but not in the sense of his juvenile religiosity. For he conceived God no longer as a personal deity who rewards or punishes men but rather, similarly to Spinoza's *deus sive natura*, as a superior intelligence which reveals itself in the harmony and beauty of nature. He fully agreed with Moses Maimonides, who in his *Guide of the Perplexed* denied categorically any corporeality of God, and with Maimonides' so-called "negative theology" which applies the method of double negations in order to avoid any personification of God. Furthermore, Einstein steadfastly resented to be regarded as an atheist and even expressed his highest regard for the ethical idealism of the theistic religions like Judaism or Christianity. In short, Einstein was a profoundly religious person, but not in the conventional sense of this term. He was, as he called himself, "a deeply religious unbeliever."

The talk also reports how Einstein's presentations of his religious *credo* have been accepted by the general public and by professional theologians. It concludes with some remarks about the question of how far, if at all, Einstein's religious sentiment had some relation with his scientific work and conforms with his famous statement that "science without religion is lame, religion without science is blind."

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