

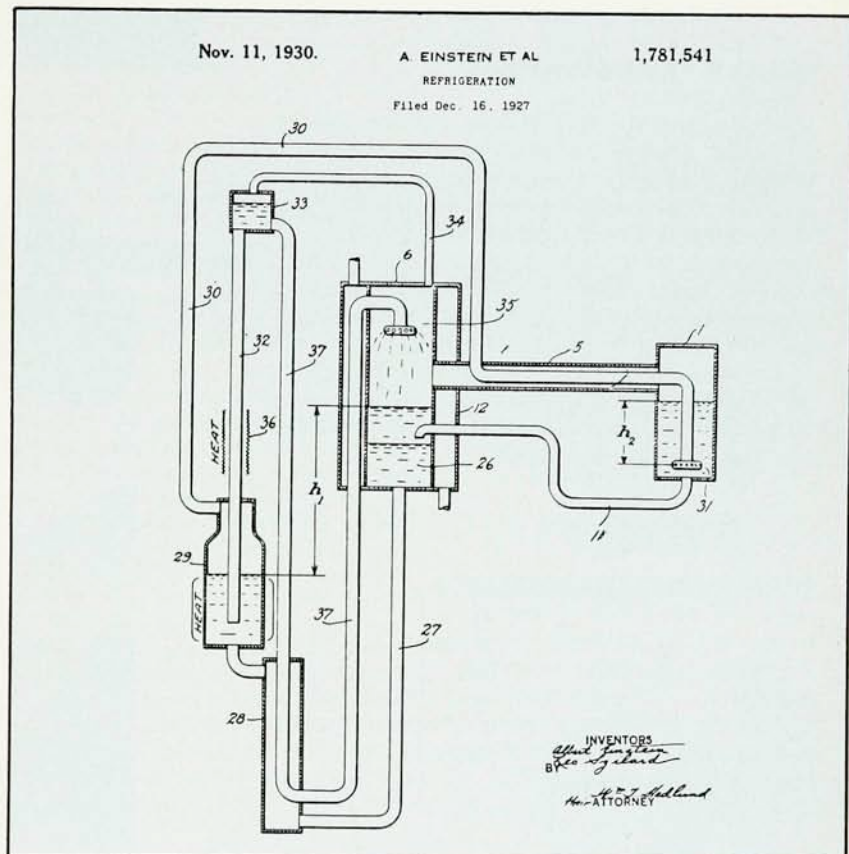
guest comment

Einstein as inventor

Georg Alefeld

If I tell people that Einstein invented several important technical devices, usually their reaction is, "Oh yes, he worked at the Swiss patent office in Berne before he made his contributions to theoretical physics." Two things are wrong: First, working at a patent office by no means implies inventive activities and, second, Einstein made his inventions long after he published his important achievements in relativity, thermodynamics and quantum physics. It was nearly a decade after he received the Nobel prize that his inventions were patented. Figure 1 shows his first invention and figure 2 shows a partial list of his patents. The number of papers the 45-50 year-old Einstein published in the patent literature¹⁻¹⁹ exceeds by far the number he published in scientific journals. In cooperation with Leo Szilard, his junior by 19 years, the theoretical physicist Einstein had a period of imaginative technical inventions. The patents are more than amusing to read. With the upcoming energy shortage they have received new remarkable relevance, in addition to the fact that some inventions have resulted in hardware that is in widespread use in modern industry.

All Einstein's inventions (except for two) are more or less related to improvements of heat pumps, which in the 1920's were almost exclusively used for refrigeration purposes. Einstein and Szilard started in 1926 with a new concept for the absorption heat pump (figure 1). Although the first absorption heat pump was built as early as 1810 by the Scotsman John Leslie (using water as refrigerant and sulfuric acid as absorbent) the thermodynamic processes involved are still considered complicated today. The work required to lift a certain amount of heat from a lower temperature level to a higher one is not provided as work, as it is for the compressor heat pump, but as heat which has the ability to do work. It can be shown²⁰ that the absorption heat pump consists of two interconnected power cycles; a left-turning (that is, work-consuming) Clausius-Rankine cycle as the real pump and a right-turning (that is, work-producing) two-component Clausius-Rankine cycle as the power



Absorption heat pump without a mechanical pump was first invention of Einstein & Szilard in 1926. Included are generator (29), evaporator (1), condenser & absorber (6).

Figure 1

station. If the pressures and temperatures for the two cycles are suitably chosen, the two cycles can be connected using one common working fluid and eliminating the turbine and the compressor. Four vessels remain: in the work-absorbing cycle the condenser and the evaporator containing the working fluid, and in the work-producing cycle the generator and the absorber containing mixtures of the working and the absorber fluid. The generator and condenser are at high pressure, evaporator and absorber at low pressure. Therefore, a mechanical pump is required to bring the rich solution from the absorber to the generator.

In Einstein's and Szilard's invention (figure 1) this pump is replaced by a third

fluid used as an auxiliary inert gas allowing all parts of the apparatus to be at the same pressure. The fluid is circulated by gravity and a bubble pump in the generator. In contrast to a similar invention by von Platen and Munters that used hydrogen as an inert gas and $\text{NH}_3/\text{H}_2\text{O}$ as working and absorbing fluids, Einstein and Szilard used a condensable gas as pressure equalizing medium. If a refrigerant that does not mix in the liquid state with the pressure equalizing medium is used, this procedure surprisingly eliminates not only the pump and throttle valves but allows the condenser and ab-

Georg Alefeld is professor of physics at Technische Universität München.

GROW WITH PHI[®] IN MBE!

PHI HAS THE PEOPLE ...

Members of the MBE scientific staff at PHI have years of experience in MBE and semiconductor development. They can answer any questions you may have regarding epitaxial growth and how it relates to state-of-the-art devices.



PHI HAS THE EQUIPMENT ...

The PHI Model 400 MBE System was designed to advance the state of MBE technology, with the researcher in mind. Features include rapid substrate insertion and retrieval, optimized vacuum pumping including closed-cycle He cryopumping of the growth chamber, accurate and continuous thermal and electrical contact during the entire growth sequence, cryoshrouded growth chamber, and in situ film characterization. The Model 400 has grown GaAs films with electron mobilities exceeding $34,000 \text{ cm}^2/\text{v-s}$ at LN_2 temperatures. Tightly controlled doping levels are also routine in the Model 400.



PHI HAS THE DIAGNOSTICS ...

In situ RHEED and RGA permit real-time monitoring of film growth and beam flux. Scanning Auger, SIMS, and ESCA equipment, all manufactured by PHI, can be mounted in the analysis chamber to evaluate substrate cleanliness and other aspects of film growth.



... AND WE'RE WILLING TO PROVE IT.

If you're interested in evaluating the potential of MBE, or are deciding on which equipment to buy, our people, equipment, and diagnostics are at your disposal. We'll grow GaAs or GaAlAs films in our laboratory while you watch. We'll also characterize these films using the latest C-V and Hall-van der Pauw equipment. Further, the most advanced surface and thin film analysis laboratory in the world can be used to chemically characterize these films.

For further information, write Perkin-Elmer Corporation, Physical Electronics Division, 6509 Flying Cloud Drive, Eden Prairie, MN, U.S.A., 55344 or call (612) 941-5540.

PERKIN-ELMER
Physical Electronics



sorber to be combined into one unit (No. 6 in figure 1). Einstein and Szilard suggested butane or methylbromide as refrigerant, NH_3 as inert gas and water as absorbent for the inert gas (not for the refrigerant!).

Multi-dimensional thinking is needed to follow and analyze the individual thermodynamic steps occurring in the three-component system (for example, the expansion of the refrigerant fluid into NH_3 bubbles passing through the evaporator and the compression of the refrigerant fluid by the process of absorption of the NH_3 by water). It is not clear to us why the Platen and Munters method was chosen over Einstein's and Szilard's invention as the basis for many million refrigerators. Perhaps the speed of absorption and vaporization in the presence of a third gas was not great enough to make the idea competitive. Further inventions by Einstein and Szilard included other combinations of working fluids and an absorption refrigeration machine in which the liquid is pumped by intermittently increasing the vapor pressure.

DEUTSCHES REICH  AUSGEZEIGT AM 27. JULI 1933 REICHSPATENTAMT PATENTSCHRIFT Nr. 554 959 KLASSE 17; GRUPPE 3a 5497179 Tag der Bekanntmachung über die Erteilung des Patents: 30. Juni 1932
Dr. Leo Szilard in Berlin-Wilmersdorf und Dr. Albert Einstein in Berlin Vorrichtung zur Bewegung von flüssigem Metall, insbesondere zur Verdichtung von Gasen und Dämpfen in Kältemaschinen Patentiert im Deutschen Reich vom 26. Dezember 1927 ab
Dr. Leo Szilard in Berlin-Wilmersdorf und Dr. Albert Einstein in Berlin Elektromagnetische Vorrichtung zur Erzeugung einer oszillierenden Bewegung Patentiert im Deutschen Reich vom 1. Juni 1928 ab
Dr. Albert Einstein in Berlin und Dr. Leo Szilard in Berlin-Wilmersdorf Pumpe, vorzugsweise für Kältemaschinen Patentiert im Deutschen Reich vom 4. Dezember 1928 ab
Dr. Albert Einstein in Berlin und Dr. Leo Szilard in Berlin-Wilmersdorf Kompressor Patentiert im Deutschen Reich vom 11. September 1929 ab
Dr. Albert Einstein in Berlin und Dr. Leo Szilard in Berlin-Wilmersdorf Pumpe, vorzugsweise für Kältemaschinen Zusatz zum Patent 555 413 Patentiert im Deutschen Reich vom 15. April 1930 ab Das Hauptpatent hat angefangen am 4. Dezember 1928.
Dr. Albert Einstein in Berlin und Dr. Leo Szilard in Berlin-Wilmersdorf Kältemaschine Patentiert im Deutschen Reich vom 15. April 1930 ab

Examples of Einstein and Szilard's patents; they obtained a total of 17 patents. Figure 2

Today a new research and development program has been started (at least in Europe) with the aim of using absorption heat pumps for home heating or more generally to "transform" heat between different temperature levels under conservation of entropy. In contrast to electrically driven compressor heat pumps (for which the waste heat created in the work-producing process must be dumped at the power station), the absorber produces the "waste heat" at the temperature level and right at the place at which it can be used for heating. As a result, the efficiency of the absorption heat pump is better than for the electrically driven compressor heat pump. Reliability and low noise also are important requirements for domestic use. Therefore, Einstein's and Szilard's ideas should attract new interest, especially since many more combinations of working fluids are known today. Just recently some of their ideas have been applied on technical scale by the Institut Français du Pétrole to upgrade industrial waste heat at a temperature level T_1 to a higher, more useful, temperature level T_2 .

The subsequent patents of Einstein and Szilard deal with improvements of the compressor heat pump. Again the procedure of pumping the fluid—or more precisely, the compression of the gas—had attracted the authors' attention. Due to their invention of an electromagnetically driven liquid-metal pump it was possible to design hermetically sealed compressor heat pumps without any mechanically moving parts and without the problems of interaction between refrigerants and lubricants. This liquid metal pump, which originally was invented to improve refrigerators, has today become an important technical device with continuously increasing applications, such as a valve, plug or pouring device for liquid metals like aluminum or magnesium alloys or as a pump in sodium-cooled breeder reactors or solar towers.

Einstein and Szilard, in later inventions, concentrated on technical details such as how to keep the metal in the liquid state during periods of interruptions or how to start the pump, and so on. As a by-product Szilard and Einstein invented an electromagnetic motor to produce linear oscillatory motions instead of rotary motions. The principle of this invention, in which springs reverse the motion, looks just tailor-made for application as a generator or motor for the recently developed, and very promising, free-piston Stirling machine in which the cylinders oscillate against gas springs.

There is no doubt that Einstein's and Szilard's contribution in the field of linear electromagnetic devices has stimulated the development of linear motors, which today are the basis for the propulsion of magnetic levitation trains.

For completeness we should mention that Einstein held a patent together with

NanoSpec/AFT

AUTOMATIC FILM THICKNESS GAUGE



non-destructively
measures
oxides
nitrides
resists
polysilicons
in a



3.5 micron spot!

Easy-to-use system
prints out thickness
within 10 seconds.

Write or call for complete information:



NANOMETRICS INCORPORATED

930 West Maude Avenue
Sunnyvale, California 94086
(408) 735-1044

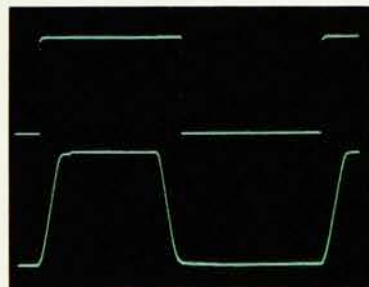
Circle No. 10 on Reader Service Card

Introducing a New Standard in Automatic Waveform Measurement: the 7612D Programmable Digitizer.

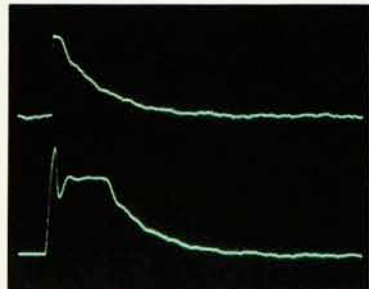
Full performance on two channels.

The Tektronix 7612D sets new standards for accuracy and measurement power in waveform digitizers. This 8-bit dual-channel dual time-base digitizer samples at rates up to 200 MHz. With crystal-controlled clock, high capacity internal memory, and full programmability, the 7612D measures up to the most demanding signal processing needs.

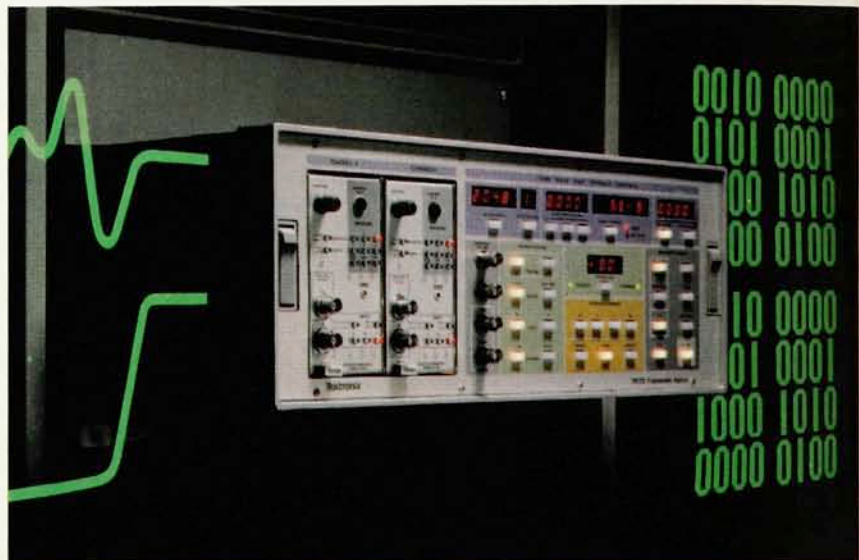
What's more, you get that performance on two channels. You can set them individually – remotely or via the front panel. Even read data from one channel while the other is acquiring data.



The complete period of a signal (top trace) is recorded at 200 ns; by changing the sample rate to 10 ns during rise and fall times and 800 ns during the plateau (bottom trace), you can measure rise time, fall time, pulse width, and interval accurately on a single shot signal.



A decaying signal recorded at a 10 μ s sampling rate (top trace); the same signal can be recorded at a 100 ns sampling rate during the initial portion, and switched back to a 10 μ s sampling rate (bottom trace), to capture all information on a single shot signal.



Easily captures the signals you want.

The 7612D provides measurement versatility that goes beyond the power of conventional oscilloscopes. Its variable sampling rate can be used to examine waveform components of interest and even capture signals with multiple echoes. All in one shot, with the touch of a few buttons.

You can capture successive randomly occurring signals by partitioning each channel into 2 to 8 records. And, to examine waveform components before or after the trigger, use the variable pre-/post trigger.

Microprocessor control and GPIB compatibility for automated operation.

Fully programmable, the 7612D can be easily integrated into an automated measurement system with a GPIB compatible controller and specialized instruments. Computer control enables highly repeatable measurements and reduces human error. For maximum measuring and

processing power, use the 7612D in a complete Signal Processing System from Tektronix. Integrated system components work together to acquire signals, make computations, and then display, document, and store your results.

For a free brochure on how the 7612D measures up against your waveform acquisition needs, call your nearest Tektronix Field Office or write: Signal Processing Systems

U.S.A.
Tektronix, Inc.
P.O. Box 1700
Beaverton, OR 97075
Phone: 503/644-0161
Telex: 910-467-8708
Cable: TEKTRONIX

**Africa, Europe
Middle East**
Tektronix Int'l, Inc.
European Marketing Center
Postbox 827
1180 AV Amstelveen
The Netherlands
Telex: 18312

**Asia, Australia, Canada, Central &
South America, Japan**
Tektronix, Inc.
America's/Pacific
P.O. Box 500
Beaverton, OR 97077
Telex: 910-467-8708
Cable: TEKTRONIX

Copyright © 1979, Tektronix, Inc. All rights reserved. 880

Tektronix®
COMMITTED TO EXCELLENCE

quest comment

G. Bucky¹⁸ on a light intensity self-adjusting camera. There is also a patent together with R. Goldschmidt on a hearing aid.¹⁹

Einstein is often described as having had a very theoretically oriented mind. In spite of this he was apparently interested and had fun in designing hardware. The sequence of the names on the patents in figure 2 as a function of time indicates how much he identified himself with this work. W. Gerlach²¹ recalled that he once met Einstein in Berlin feeling quite depressed: the patent office had informed him that a refrigerator that he and Szilard had conceived was known and thus could not be patented. What a new experience for a man like Einstein having a "publication" being turned down and declared as previously known. In his own words: "If this would have happened to the theory of Special Relativity . . ."

References

1. A. Einstein, L. Szilard, *Refrigeration* (Appl.: 16 Dec. 1927; Priority: Germany, 16 Dec. 1926). Pat. No. 1 781 541 (United States), 11 Nov. 1930.
2. A. Einstein, L. Szilard, *Improvements Relating to Refrigerating Apparatus* (Appl.: 16 Dec. 1927; Priority: Germany, 16 Dec. 1926). Pat. No. 282 428 (United Kingdom). Complete accept.: 5 Nov. 1928.
3. L. Szilard, A. Einstein, *Refrigerating Machines in which the Pumping of Liquid is Effected by Intermittently Increasing the Vapour Pressure* (Appl. 29 Dec. 1927; Priority: Germany, 29 Dec. 1926). Pat. No. 282 808 (United Kingdom). Complete not accepted.
4. A. Einstein, L. Szilard, *Refrigerating Machine with Organic Solvent* (Appl. 24 Jan. 1928; Priority: Germany, 24 Jan. 1927). Pat. No. 284 222 (United Kingdom). Complete not accepted.
5. L. Szilard, A. Einstein, *Improvements in Refrigerating Processes and Apparatus* (Appl. 10 July 1928; Priority: Germany, 14 July 1927). Pat. No. 293 865 (United Kingdom). Complete accept. 30 May 1929.
6. A. Einstein, L. Szilard, *Kältemaschine* (Einger.: 12. Nov. 1927). Pat. Nr. 563 403, Klasse 17a, Gruppe 3 (Deutsches Reich), 20. Okt. 1932.
7. L. Szilard, A. Einstein, *Vorrichtung zur Bewegung von flüssigem Metall insbesondere zur Verdichtung von Gasen und Dämpfen in Kältemaschinen* (Einger.: 27. Dez. 1927). Pat. Nr. 554 959, Klasse 17a, Gruppe 3 (Deutsches Reich) 30. Juni 1932.
8. A. Einstein, L. Szilard, *Electrodynamic Movement of Fluid Metals Particularly for Refrigerating Machines* (Appl. 24 Dec. 1928, Priority: Germany, 27 Dec. 1927). Pat. No. 303 065 (United Kingdom). Complete accept. 26 May, 1930.
9. A. Einstein, L. Szilard, *Werkwijze voor het comprimeeren van den damp van het koudmakend middel in een koelmachine en koelmachine, geschikt voor de toe-*
- passing van deze werkwijze (Ingediend: 27 Dec. 1928, voorrang: 27 Dec. 1927, Deutschland). OCTROOI No. 31163 (Nederland), Klasse 17a, Uitgegeven: 15. Nov. 1933.
10. A. Einstein, L. Szilard, *Kältemaschine* (Einger. 21. Dez. 1928, Priorität: Deutschland, 27. Dez. 1927). Pat. Nr. 140 217, Klasse 108 a (Schweizerische Eidgenossenschaft), 31. Mai 1930.
11. L. Szilard, A. Einstein, *Elektromagnetische Vorrichtung zur Erzeugung einer oszillierenden Bewegung* (Einger.: 31. Mai. 1928). Pat. Nr. 562 040, Klasse 21d, Guppe 18 (Deutsches Reich), 6. Okt. 1932.
12. A. Einstein, L. Szilard, *Pumpe, vorzugsweise für Kältemaschinen* (Einger.: 3. Dez. 1928). Pat. Nr. 555 413, Klasse 17a, Gruppe 3 (Deutsches Reich), 7. Juli 1932.
13. A. Einstein, L. Szilard, *Pump, especially for Refrigerating Machines* (Appl.: 3 Dec. 1929, Priority: Germany, 3 Dec. 1928). Pat. No. 344 881 (United Kingdom). Complete accept.: 3 March 1931.
14. A. Einstein, L. Szilard, *Kompressor* (Einger.: 10. Sept. 1929). Pat. Nr. 565 614, Klasse 17a, Gruppe 3 (Deutsches Reich), 17. Nov. 1932.
15. A. Einstein, L. Szilard, *Pumpe, vorzugsweise für Kältemaschinen* (Einger.: 14. April 1930). Pat. Nr. 556 535, Klasse 17a, Gruppe 3 (Deutsches Reich), 21. Juli 1932.
16. A. Einstein, L. Szilard, *Kältemaschine* (Einger.: 14. April 1930). Pat. Nr. 561 904, Klasse 17a, Gruppe 3 (Deutsches Reich), 29. Sept. 1932.
17. A. Einstein, L. Szilard, *Kältemaschine* (Einger.: 14. April 1930). Pat. Nr. 562 300, Klasse 17a, Gruppe 1 (Deutsches Reich), 6. Okt. 1932.
18. G. Bucky, A. Einstein, *Light intensity self-adjusting camera* (Appl.: 11 Dec. 1935). Pat. No. 2 058 562 (United States), 27 Oct. 1936.
19. R. Goldschmidt, A. Einstein, *Vorrichtung, insbesondere für Schallwiedergabegeräte, bei der elektrische Stromänderungen durch Magnetostriktion Bewegungen eines Magneten hervorgerufen werden* (Appl.: 25 April 1929, Pat. No. 590 783 Klasse 21a² Gruppe 1/04 (Germany), 10 Jan. 1934).
20. G. Alefeld, *Energie 30*, 398(1978); *Festkörperprobleme* (Advances in Solid State Physics), 18, 53(1978).
21. W. Gerlach, in *Albert Einstein, Sein Einfluss auf Physik, Philosophie und Politik*, (P. C. Aichelburg, R. U. Sexl, eds.) Vieweg Braunschweig-Wiesbaden 1979; page 206.

* * *

Based on a talk at the Joint Meeting of the Austrian, German and Swiss Physical Societies, Ulm, 1979. □

INHOMOGENEOUS SUPERCONDUCTORS-1979

(Berkeley Springs, W.V.)

AIP Conference Proceedings #58

EDITORS: D.U. Gubser, T.L. Francavilla,

S.A. Wolf, J.R. Leibowitz

325 pages. 1979. \$20.50 clothbound.

LC 79-57620. ISBN 0-88318-157-6.

Send orders to: American Institute of Physics, Marketing Services, 335 East 45 Street, NY, NY 10017.

DENTON VACUUM

THE AMERICAN MANUFACTURER WITH OPTICAL COATING EXPERIENCE

DENTON VACUUM'S EQUIPMENT DESIGN IS BASED ON OUR EXTENSIVE IN HOUSE OPTICAL COATING EXPERIENCE

STANDARD AND CUSTOM MADE

- Box Coaters
- Bell Jar Systems
- Sputtering Systems
- Manual - Automatic
- Substrate Tooling
- Planetary Rotary Turn-Over
- Rate-Thickness Controls
- Optical Monitors
- E.B. - Resistance - Sputtering Sources
- Single Source Responsibility

CUSTOM COATING SERVICE



Cherry Hill Industrial Center
Cherry Hill, NJ 08003
609/424-1012

Circle No. 12 on Reader Service Card