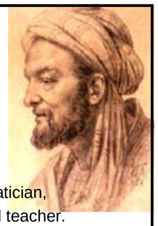
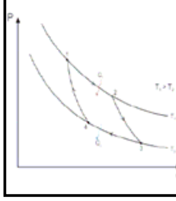
Avicenna
(c. 980 – 1037)



- Persian polymath; the foremost physician and philosopher of his time. He was also an astronomer, chemist, geologist, logician, paleontologist, mathematician, physicist, poet, psychologist, soldier, statesman, and teacher.
- He invented the refrigeration coil, which condenses aromatic vapors.
- This was a breakthrough in distillation technology and he made use of it in his steam distillation process to separate temperature sensitive material and produce essential oils.

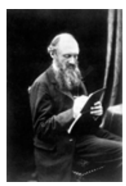
Nicolas Léonard Sadi Carnot
(1796 – 1832)

- Proposed Carnot Engine in 1824 on which Carnot Cycle was modeled
- From Carnot Cycle came the concept of Heat Pump which follows Carnot Engine working in reverse (Carnot Cycle anti-clockwise)
- Later in 1852 Lord Kelvin built the first Heat Pump



Development of the Kelvin Absolute Temperature Scale

- William Thomson (later Lord Kelvin) was interested in Charles's Law which states that when a gas is cooled by one degree Celsius, it's volume drops by 1/273
  - This would lead to zero volume at -273°C
  - How can matter exist without taking up space?
- Thomson instead suggested that it was the energy of motion that decreased with temperature
  - At -273°C, the molecules cease motion and essentially not take up space
  - He called -273°C absolute zero because no further temperature reduction is possible. This later became known as 0 Kelvin.


Lord Kelvin

Sources: University of Glasgow and World of Scientific Discovery

Liquefaction of Oxygen

Liquid oxygen is the liquid form of element oxygen. In nowadays it is widely used in many fields.

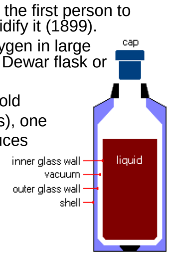
Liquefaction of substance that normally exists as gas dates back to the 18th century. The first successful attempt was made by a French mathematician Gaspard Monge, who liquefied sulfur dioxide in 1784. In the following decades, people succeeded in liquefy many gases, but none of them was able to liquefy oxygen gas. In the late 1840s, Irish physical chemist Thomas Andrews suggested that every gas has a precise temperature, which is the critical temperature. Above the temperature gas cannot be liquefied even under great pressure. Following Andrews idea, scientist came up with the idea of using 'cascade' process to get low temperature. In this method, one liquefied gas is used to cool another gas with lower critical temperature, and so on. By using the cascade process, French physicist Louis Paul Cailletet liquefied three gases, oxygen, nitrogen and carbon monoxide.

Now liquid oxygen is playing a significant role in both industry and research. Compare with oxygen gas, liquid oxygen is much easier to store and transport. Liquid oxygen is stored in hospitals for patients with breathing problems. It is also used as oxidizer in industry, such as producing ion and many other metals. Furthermore, liquid oxygen is used as oxidizer in spacecraft such as rockets. Without liquefaction of oxygen, one cannot provide enough oxygen with such limited space and cannot put rocket into use.

Liquefaction of oxygen is an important event in the history. It was one of the human first attempts to liqeify 'permanent gas'. Liquid oxygen also serves as an important substance today.

Dewar, Sir James
(1842 – 1923)

- Scottish chemist and physicist; best known for his work with low-temperature phenomena.
- He studied the specific heat of hydrogen and was the first person to produce hydrogen in liquid form (1898) and to solidify it (1899).
- He constructed a machine for producing liquid oxygen in large quantities in 1891 and subsequently invented the Dewar flask or thermos in 1892.
- The Dewar flask is a container for storing hot or cold substances. It consists of two flasks (usually glass), one inside the other, separated by a vacuum that reduces the transfer of heat, preventing a temperature change.



Sir James Dewar
(1842–1923)

Invented Vacuum flask in 1892

$$\eta = \langle v \rangle \langle l \rangle \rho = \frac{1}{n\sigma}\sqrt{\frac{8kT}{\pi m}}mn = Const\sqrt{T}$$

Why vacuum? L ~ size

James Dewar

Invented a silvered, double walled, glass vacuum vessel to contain cryogenic liquids for the first time, for relatively long periods, before they evaporated.

Most widely known in connection with his work on the liquefaction of the so-called permanent gases and his researches at temperatures approaching absolute zero.

His work was used to help create vapor-cooled radiation shields and multilayer insulations

Received Hodgkins Gold Medal for his work on liquid oxygen and liquid hydrogen

1842-1923

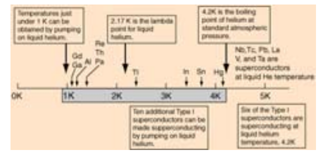
Important events in the history of civilization, related to cryogenics

(1908) Heike Kamerlingh Onnes liquefies helium

Born	Heike Kamerlingh Onnes 21 September 1853 Groningen, Netherlands
Died	21 February 1926 (aged 72) Leiden, Netherlands
Nationality	Netherlands
Fields	Physics
Institutions	University of Leiden Heidelberg University University of Groningen
Known for	Onnes-effect
Notable awards	Nobel Prize in Physics (1913)

- Commonly used cryogenic refrigerant in physics experiments and applications
- It has very interesting properties like superfluidity
- Led to the discovery of superconductivity

Liquid Helium in a cup



- It cools down lossless superconducting magnets used in modern technological applications

The Discovery of Superconductivity

-Discovered 1911

-Won Onnes Nobel in 1913

-First superconducting Materials:

1. Mercury (Gold deemed too hard to refine) (4.2K)
2. Lead (7 K)
3. Niobium Nitride (16 K)

-Made possible by liquefaction of Helium and Dewar containers

-Used to prove Tesla's Patent of low temperature resonating circuit

Heinke Kamerlingh Onnes

Heike Kamerlingh Onnes

the first person to liquify helium

21 September 1853 – 21 February 1926

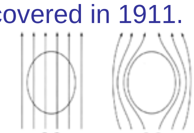
From 1871 to 1873,He studied under Robert Bunsen and Gustav Kirchhoff at the University of Heidelberg

In 1908, Heike Kamerlingh Onnes successfully liquified helium by using the Joule-Thomson effect. He lowered the temperature to less than one degree above absolute zero. At that time this was the coldest temperature achieved on earth.

Heike Kamerlingh Onnes

Superconductivity was discovered in 1911.

- H. K. Onnes was studying the resistance of mercury using the recently-discovered liquid helium as a refrigerant.
- when mercury was cooled down to 4.2 K, he observed that the resistance abruptly disappeared.
- Superconductors show a property of perfect diamagnetism, which is called the Meissner Effect.



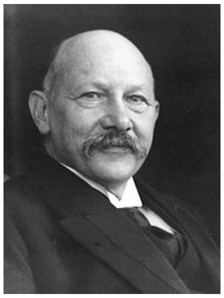
Unlike a normal state, magnetic flux can't penetrate a superconducting state.

Meissner effect: levitation of a magnet above a superconductor

Discovery of Superconductivity and Its Applications

- 1908, Kamerlingh Onnes first liquefied helium-4, which led to his discovery of type I superconductivity (not possible for applications because of low T_c and H_c) in 1911.
- 1961, discovery of type II superconductor with higher T_c and H_c, making applications possible.
- 1986, discovery of ceramic high temperature superconductors (HTS) with T_c above the liquid nitrogen boiling point.
- Current applications: superconducting magnets used in MRI and NMR machines, particle accelerators; SQUIDs; magnetic levitation; HTS wires, etc.
- Possible future applications: high performance transformers, power storage devices, electric power transmission, electric motors, etc.

Discovery of Superconductivity



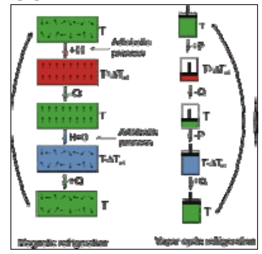
- Heike Kamerlingh Onnes
- Made possible by the recent discovery of liquid helium as a refrigerant
- First discovered super conductive material: Mercury

1933: Temperature of .25K Reached

•Several groups were able to cool past .3K with magnetic cooling.

•The technique uses adiabatic demagnetization. First suggested by Debye (1926) and Giauque (1927).

•The process is in use today both in industry, where it has been adapted to work at room temperature, and in research, where substances can be cooled to micro Kelvin.

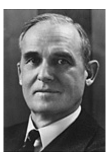


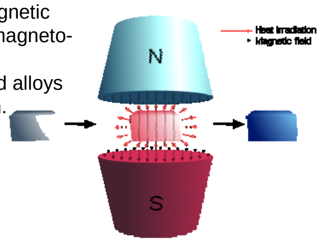
http://en.wikipedia.org/wiki/Magnetic_refrigeration

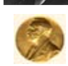
Magnetic Refrigeration

W. F. Giauque and D. P. MacDougall, 1933

Temperature change in material caused by changing magnetic field via the magneto-caloric effect. Giauque used alloys of gadolinium.





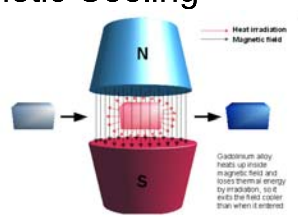


1949 Nobel Prize in Chemistry

Magnetic Cooling

Peter Debye

William Frances Giauque



- Independently theorized by Debye in 1926 and Giauque in 1927
- Adibatic demagnetization first demonstrated by Giauque in 1933
- Allowed for temperatures below 1K to be reached for the first time

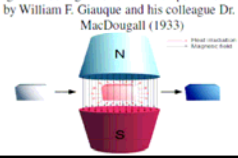
By Ishmal Lewis

Magnetic refrigeration

- discovered in pure iron in by Emil Warburg (1881)
- adiabatic demagnetization Debye (1926) and Giauque (1927)

William Francis Giauque(1895- 1982)

- Magnetic cooling used to reach temperatures below 1K by William F. Giauque and his colleague Dr. D.P. MacDougall (1933)

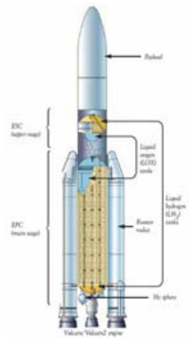


Tupolev Tu-155

Russian Tupolev created the first commercial passenger jet that is partially fueled with liquid hydrogen. After only a few flights, the plane was changed to instead run on cooled liquid natural gas. The frequency with which we fly about in a Tupolev perhaps hints as to the level of success of this plane.

Cryogenics in Space Transportation

- Space Cryogenics is the application of cryogenics to space missions.
- Liquid hydrogen and liquid oxygen are used in the main engines of the Shuttle because they offer a very high specific impulse.
- These propellants are cryogenic with normal boiling points of 20 kelvin (-253°C) and 90 kelvin (-183°C) respectively.
- For the Shuttle, these propellants are stored in the poorly insulated external tank.



Peter Debye

•In 1934, he became director of the Kaiser Wilhelm Institute for Physics (Max-Planck-Institut).

•He studied under Arnold Sommerfeld, who claimed that his most important discovery was Peter Debye.

•Created the Debye Model which gives a good approximation for low temperature heat capacity of insulating, crystalline solids.

1906- Willis Carrier patents “Apparatus for Treating Air”

- First unit installed in a Buffalo, NY printing shop, where fluctuations in humidity were causing problems
- Carrier understood how temperature/humidity and dew point were related
- Used ammonia as a cryogenic
- Not the first true air conditioner, but Carrier's

Freezing of Foods

Clarence Birdseye

History of Freezing Foods

1926 – Quick Freeze Machine was unvei

1944 – Use of refrigerated boxcars to transport frozen foods by rail bega

Today – Cryogenic freezing of food produ

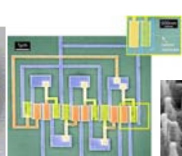
Birdseye developed a freezing process to preserve food as well as its taste and appearance called flash freezing. This is a method where items are frozen so fast that only small ice crystals are able to form. The cell walls are not damaged and the frozen food, when thawed, keeps its maximum flavor, texture, and color.

Information taken from birdseyefoods.com

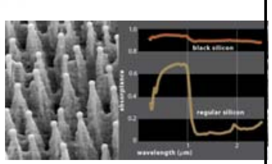
Cold Electronics

In the 1980s a discovery at Southampton and elsewhere that CMOS silicon chips with no bipolar elements will operate at low temperatures enables previously unattainable precision levels of measurement (to less than one part in 10,000) to be made routinely in cryogenic systems.

Two examples of sensors made with this type of silicon, one being a finger print sensor, the other the a micro weight sensor.

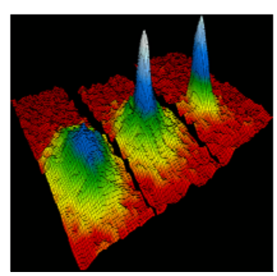


Close up picture of Black CMOS Silicon which is made in temperatures up to 40 Kelvin, said to be 100 more accurate in sensors then other types of silicon



Bose-Einstein condensed state

- First predicted by Satyendra Nath Bose and Albert Einstein in 1924-25.
- First produced by Eric Cornell and Carl Wieman in 1995.
- Using a gas of rubidium atoms cooled to 170 nK.



Steven Chu, Claude Cohen-Tannoudji, & William Phillips

Development of methods to cool and trap atoms with Lasers (1997 Nobel Prize)

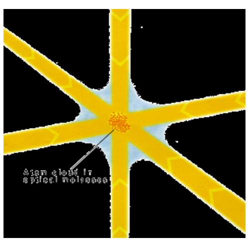
- Findings enable researchers to study and gain knowledge with great precision.
- Shining the wavelengths of the laser light slows the atoms down, which cool them. (Optical Molasses)
- Atomic lasers may help in the future to manufacture tiny electronic components.

Laser Cooling

- Laser light is detuned to a frequency slightly lower than resonance.
- Due to the Doppler Effect, only atoms moving toward the light will absorb the photons and be slowed down by the photon's momentum.
- Steven Chu, Claude Cohen-Tannoudji, and William D. Phillips were awarded the 1997 Nobel Prize in Physics for their work in laser cooling.

A cloud of cold sodium atoms (bright spot at center) floats in a

Laser Cooling



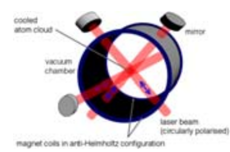
Courtesy to wikipedia

Starting with a warm cloud of atoms and a laser frequency well below the resonant frequency. Due to Doppler effect, the light is detuned blue (higher frequency) for the incoming atoms. Thus for these atoms, the photons in the **opposite** direction could reach resonant frequency and be absorbed. Hereby the atoms are slowed down and we cool the atoms.

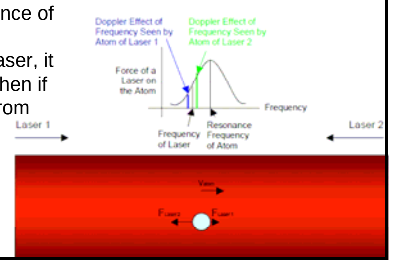
Steven Chu, Claude Cohen-Tannoudji and William D. Phillips were awarded the 1997 Nobel Prize in Physics for this.

Courtesy to wikipedia

Magneto-Optical Trap -1987

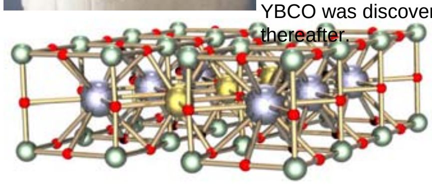


•A way to cool neutral atoms to about 100µK and is used for making BECs.
•Uses the fact that photons carry momentum and the Doppler Effect to slow down atoms.
•The a laser frequency is detuned off the resonance of an atom. If the atom is traveling towards the laser, it will feel a larger push then if it was traveling away from the laser.
•A magnetic field well is used to prevent the slow moving atoms in the middle from drifting away.



High-Temperature Superconductors

In 1986 Johannes Georg Bednorz and Karl Alexander Müller discovered superconductivity in a lanthanum-based cuprate perovskite material, which had a transition temperature of 35 K (Nobel Prize in Physics, 1987). YBCO was discovered shortly thereafter.



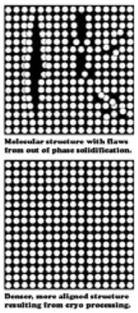
Above: A magnet floating above YBCO at 77K. Below: YBCO

Cryogenic Hardening

Ed Busch founded the first commercial cryogenic processing industry is 1966, called CryoTech.

- Cryogenic hardening works by rearranging the structure of metals.
- It is used to improve life span of metals by 100% to 300%.
- Current uses include: Brake rotors, performance engines, transmissions, gun barrels, cutting and machine tools, and even musical instruments.

Cryogenic Hardening

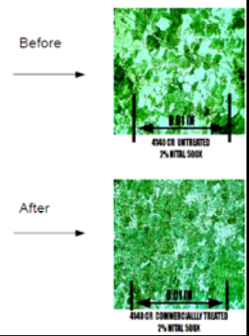


- Hardening of steel involves heating to an elevated temperature where a crystalline phase termed austenite is stable. If the austenite is cooled at a sufficient rate, it will transform to a much harder and stronger phase known as martensite.
- Marensite is highly organized and stable, which gives it its strength and hardness.
- Martensite has a body centered tetragonal crystal structure, whereas austenite has a face

Cryogenic Tempering (1940's)

- Materials are super-cooled (-300ºF) to improve their strength and durability
- Causes changes in atomic structure and grain size
- More effective than older methods such as quenching—produce more uniform result
- Inexpensive and cost-effective (5-15% tool cost)

Crystal Structures



Cryosurgery

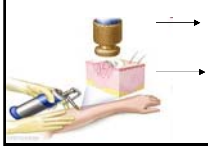
The application of extreme cold to destroy abnormal or diseased tissue

•In 1961, modern cyrosurgery came into being with the invention of the cryoprobe by physician Irving Cooper and engineer Arnold Lee

•Their device consisted of a probe that applied liquid nitrogen to the treatment site

A modern very portable cyroprobe is seen to the right

*"The CryoProbe offers the most advanced cryosurgical technique for unparalleled freezing power combined with pinpoint accuracy. It allows easy & effective treatments…..**Order Yours Today! Only $1,595!"***



THE WAY IT WORKS

•Extreme low temperatures causes ice crystals to form within the cell tearing it apart

•Used predominantly on benign and malignant skin conditions such as warts, moles, skin tags, solar keratoses, and small skin cancers

Cryosurgical probe: Irving Cooper and Arnold Lee

•Built the modern day liquid nitrogen cryosurgical probe in 1959.

•Allows liquid nitrogen to be conducted to the probe tip with precision and without heat loss.

•Originally designed to freeze brain tissue, for treatment of Parkinson's and other neural disorders.

•Cryosurgical probe resulted in rapid growth within the field of cryosurgery

•Currently mostly used in the fields of gynecology and dermatology due to the emergence of laser techniques.

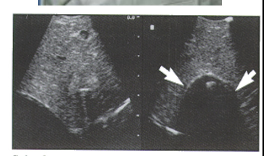
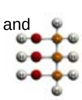


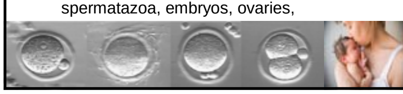
Fig 2. — Demonstration of real-time intraoperative ultrasound monitoring of hepatic cryosurgery. The left panel shows cryoprobe placement in the center of the liver tumor. The right panel shows the freezing process near completion. Hyperechoic rim and post-acoustic shadowing are evident (arrows).

The discovery of Cryoprotectants

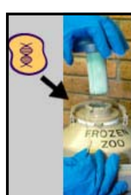
Jeremy Paster

- Glycerol, in **1946**, by Polge and Smith
- Dimethylsulfoxide (DMSO) in **1959** by Lovelock and Bishop
- Cryoprotectants protect biological tissue from freezing damage ensuring the survival of cryopreserved cells and tissues, spermatazoa, embryos, ovaries,





Frozen Zoo
a modern day Noah's Ark



San Diego's frozen zoo:

frozen, viable cell cultures, semen, embryos, oocytes and ova, blood, and tissue specimens

samples from more than 8,400 individuals

representing more than 800 species/subspecies

A frozen leopard embryo

Frozen leopard sperm

Cryonics

1962 and ongoing

- •Movement started my Robert Ettinger in 1962
- •A method of preserving the recently diseased for possible resuscitation in the future by freezing
- •Co.s such as Alcor and the American Cryonics Society provide cryonic preservation as medical care
- •Faces challenges such as tissue damage on the molecular level and cost prohibition
- •Resusitation performed by electron and photothermal microscopy.

CRYOGENICS USED TO PRESERVE LIFE

- 1964- Robert C.W. Ettinger's book, *The Prospect of Immortality*
- It is possible to preserve dead bodies with no deterioration at very low temperatures.
- It is not yet known how to revive and cure after being frozen.
- Lead to much discussion and excitement of cryogenics.
- It is believed that Walt Disney was frozen and stored underneath the Pirates of the Caribbean ride at Disney Land.

IS WALT DISNEY CRYOGENICALLY FROZEN??

http://www.snopes.com/disney/info/wd-ice.htm
By Andrea Booher

LHC – biggest, coldest thing on Earth

April 7, 2008 – 1.8 K temperature reached at critical areas.

- 31 kt of equipment, 700 kl of liquid Helium passing through 40,000 pipe junctions
- Low temperature needed for super-conducting magnets.
- Superfluid helium used to reach 1.8 K.
- Normal liquid helium could have been used - costs less and still reaches super-conductive temperatures (~4.5 K), but unusually efficient heat transfer properties of superfluid helium can be used to transport large refrigerated loads more than 1 km with a temperature drop of less than 0.1 K.