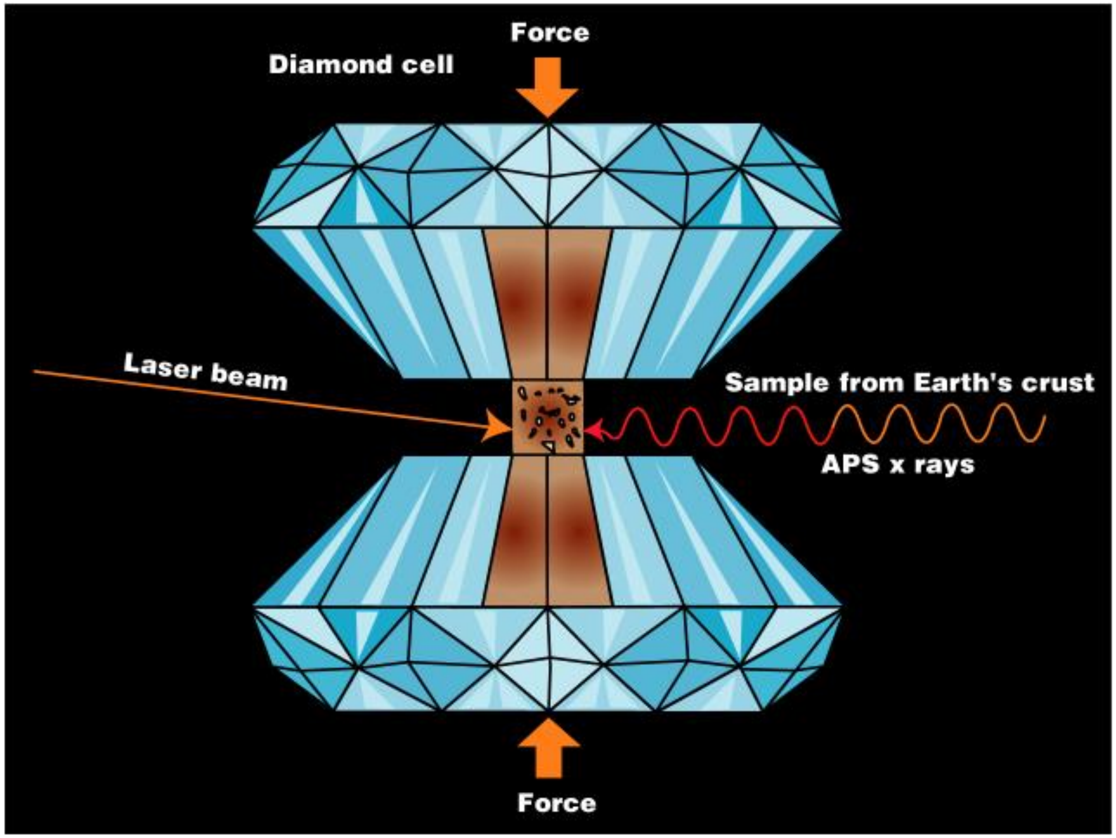
Diamond anvil cell (DAC)



K S Sugi
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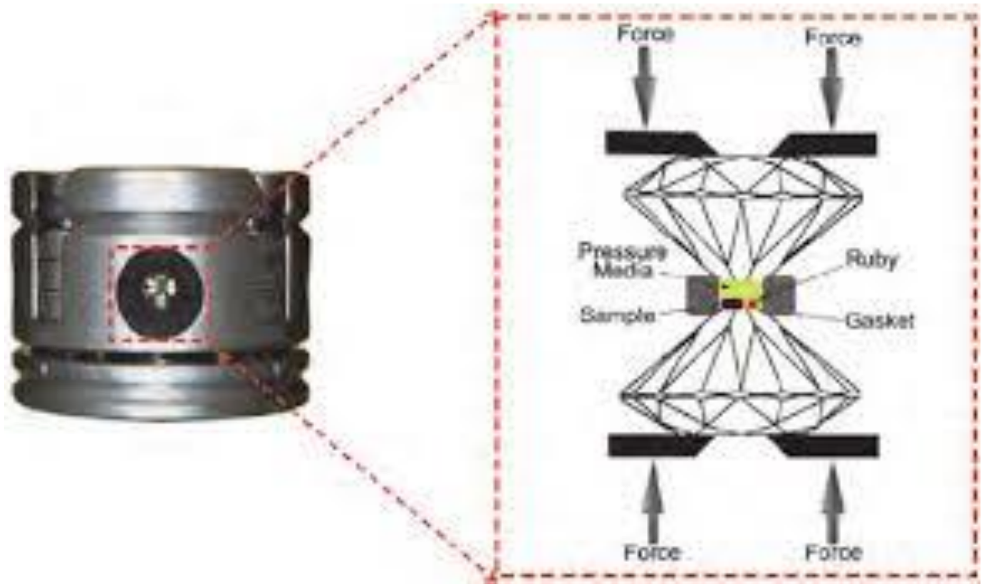
Introduction:

- A diamond anvil cell (DAC) is a high-pressure device used in scientific experiments.
- It enables the compression of a small (sub-millimeter-sized) piece of material to extreme pressures, typically up to around 100–200 gigapascals, although it is possible to achieve pressures up to 770 gigapascals (7,700,000 bars / 7.7 million atmospheres).
- The device has been used to recreate the pressure existing deep inside planets to synthesize materials and phases not observed under normal ambient conditions.
- Notable examples include the non-molecular ice X, polymeric nitrogen and metallic phases of xenon and potentially hydrogen.



Principle:

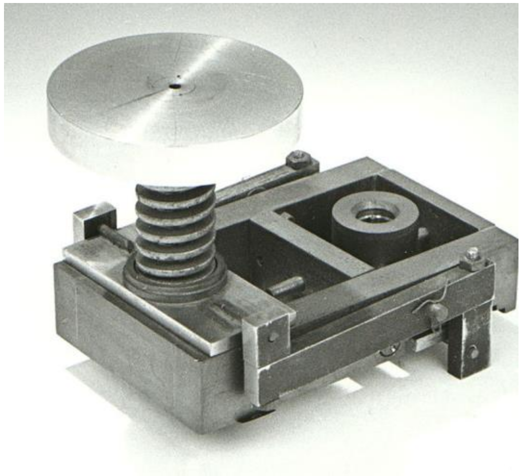
The operation of the diamond anvil cell relies on a simple principle:

$P = F/A$

where P is the pressure, F the applied force, and A the area.

Typical culet sizes for diamond anvils are 100–250 micron, such that a very high pressure is achieved by applying a moderate force on a sample with a small area, rather than applying a large force on a large area. Diamond is a very hard and virtually incompressible material, thus minimizing the deformation and failure of the anvils that apply the force.

History:



- Percy Williams Bridgman, the great pioneer of high-pressure research during the first half of the 20th century, revolutionized the field of high pressures with his development of an opposed anvil device with small flat areas that were pressed one against the other with a lever-arm. The anvils were made of tungsten carbide (WC). This device could achieve pressure of a few gigapascals, and was used in electrical resistance and compressibility measurements.

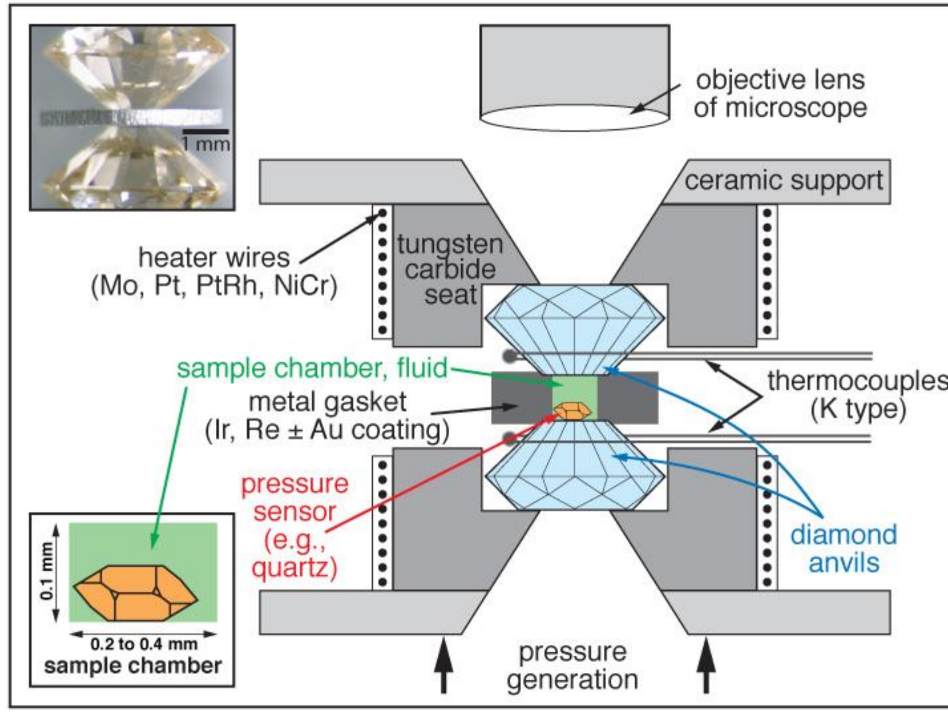
- The diamond cell was created at the National Bureau of Standards (NBS) by Charles E. Weir, Ellis R. Lippincott, Alvin Van Valkenburg and Elmer N. Bunting. Within the group each member focused on different applications of the diamond cell. The group was well established in each of their techniques before outside collaboration kicked off with university researchers like William A. Bassett and Taro Takahashi at the University of Rochester.

- During the following decades DACs have been successively refined, the most important innovations being the use of gaskets and the ruby pressure calibration.

- The range of static pressure attainable today extends to 640 GPa, much higher than the estimated pressures at the Earth's center (~360 GPa)

Major components:

- **Force-generating device**
- **Diamond anvils**
- **Gasket**
- **Pressure-transmitting medium**
- **Pressure measurement**

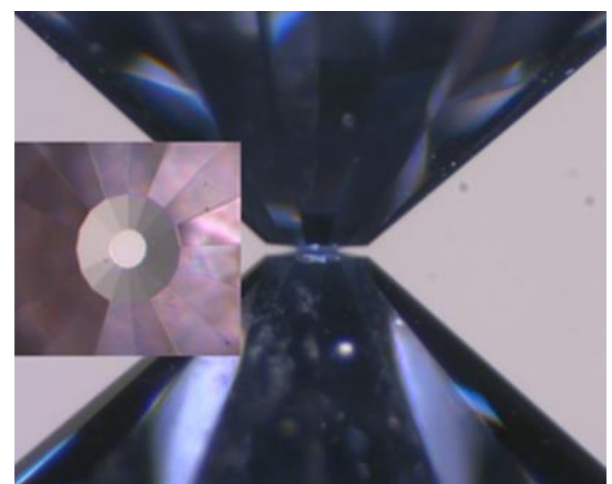


- **Force-generating device**

Relies on the operation of either a lever arm, tightening screws, or pneumatic or hydraulic pressure applied to a membrane. In all cases the force is uniaxial and is applied to the tables (bases) of the two anvils.

- **Diamond Anvils**

Made of high gem quality, flawless diamonds, usually with 16 facets, they typically weigh 1/8 to 1/3 carat (25 to 70 mg). The culet (tip) is ground and polished to a hexadecagonal surface parallel to the table. The culets of the two diamonds face one another, and must be perfectly parallel in order to produce uniform pressure and to prevent dangerous strains.



➢ Gasket

A gasket used in a diamond anvil cell experiment is a thin metal foil, typically 0.3 mm in thickness, which is placed in between the diamonds. Desirable materials for gaskets are strong, stiff metals such as rhenium or tungsten. Steel is frequently used as a cheaper alternative for low pressure experiments. if x-ray illumination through the gasket is required, lighter materials such as beryllium, boron nitride, boron or diamond are used as a gasket. Gaskets are preindented by the diamonds and a hole is drilled in the center of the indentation to create the sample chamber.

➢ Pressure-transmitting medium

The pressure transmitting medium is the compressible fluid that fills the sample chamber and transmits the applied force to the sample. A good pressure medium will remain a soft, compressible fluid to high pressure.

Gases: He, Ne, Ar, N_2

Liquids: 4:1 Methanol/Ethanol, Silicone Oil, Fluorinert, Daphne 7474 Cyclohexane

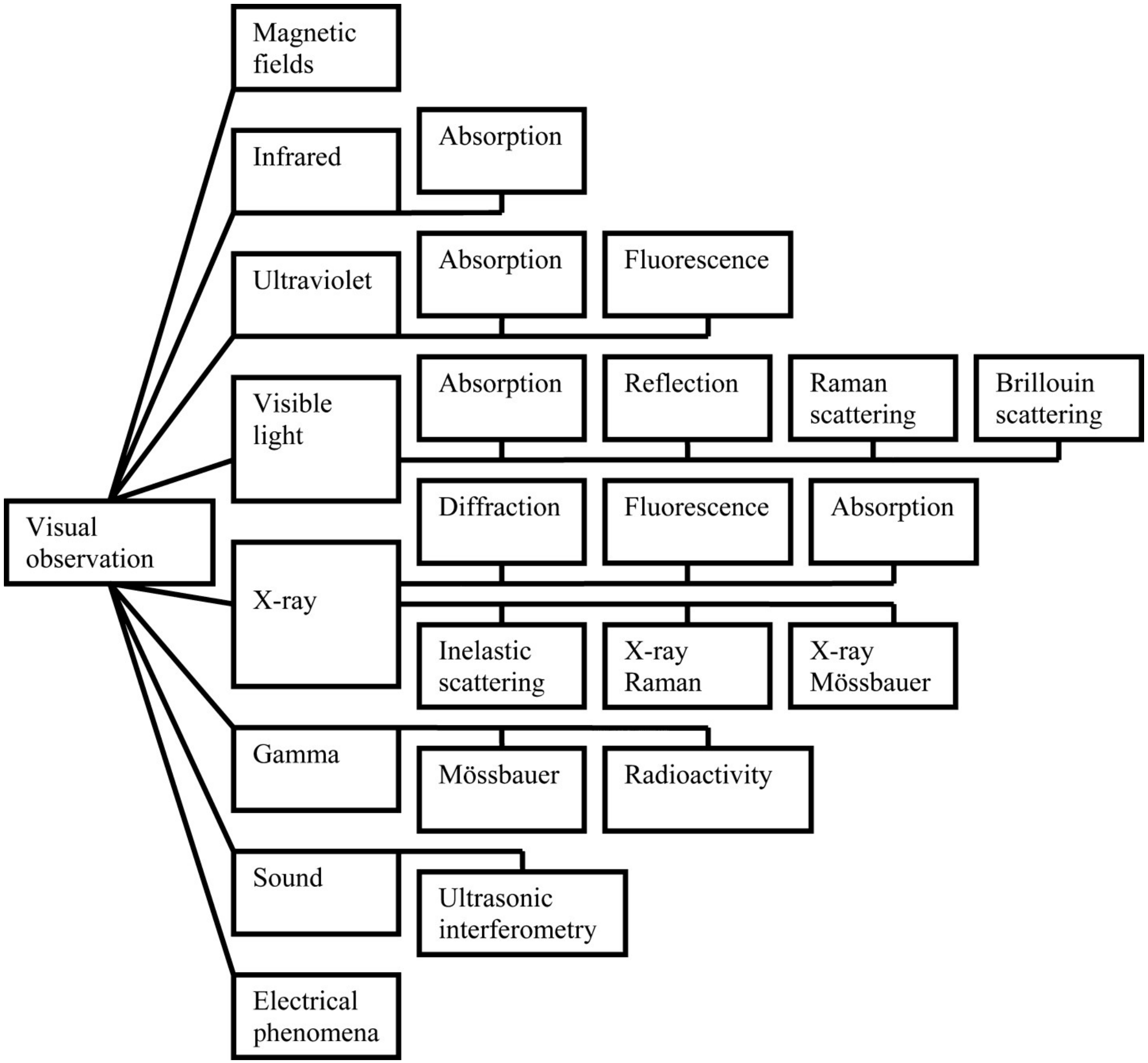
Solids: NaCl

➢ Pressure measurement

The two main pressure scales used in static high-pressure experiments are X-ray diffraction of a material with a known equation of state and measuring the shift in ruby fluorescence lines. It was found that the wavelength of ruby fluorescence emissions change with pressure, this was easily calibrated against the NaCl scale.

Experimental techniques with DAC:

The sample can be viewed through the diamonds and illuminated by X-rays and visible light. In this way, X-ray diffraction and fluorescence; optical absorption and photoluminescence; Mössbauer, Raman and Brillouin scattering; positron annihilation and other signals can be measured from materials under high pressure.



Advantages:

1. Prior to the invention of the diamond anvil cell, static high-pressure apparatus required large hydraulic presses which weighed several tons and required large specialized laboratories. The simplicity and compactness of the DAC meant that it could be accommodated in a wide variety of experiments.

2. In addition to being hard, diamonds have the advantage of being transparent to a wide range of the electromagnetic spectrum from infrared to gamma rays, with the exception of the far ultraviolet and soft X-rays. This makes the DAC a perfect device for spectroscopic experiments and for crystallographic studies using hard X-rays.

Disadvantages:

1. Sample volume is less.

2. Other relevant limitations in ultrahigh-pressure experiments are the difficulty of calibrating the local pressure, the strong nonhydrostaticity of the samples, the red shift of the diamond absorption edge which, jointly with the diamond fluorescence, puts severe limitations to the optical investigations.

References:

https://serc.carleton.edu/NAGTWorkshops/mineralogy/mineral_physics/diamond_anvil.html

http://www.rossangel.com/bergen/Miletich_DACs.pdf


Thank you!