# Measuring Stellar Fusion Reactions with UBC's Van de Graaff

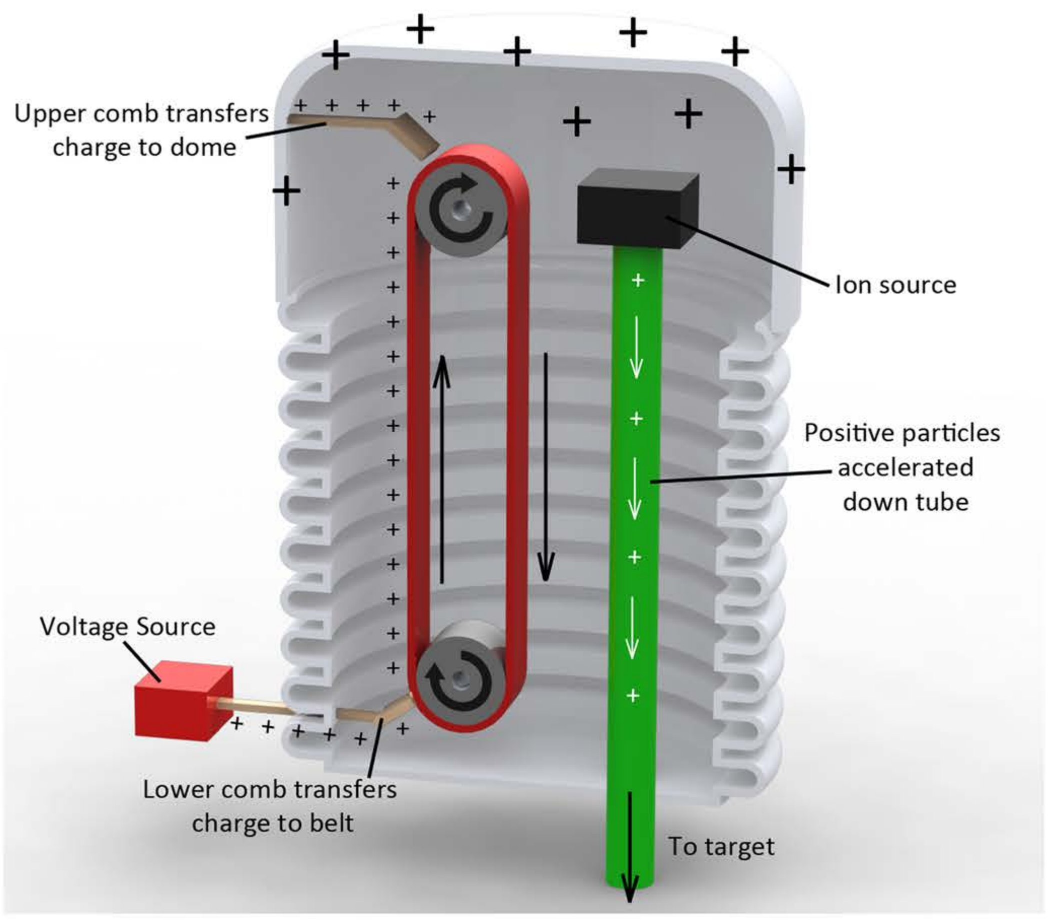
The Van de Graaff generator is a classic physics demonstration. A very large one was used in the Physics Department at UBC many decades ago to study stellar nucleosynthesis.

## How It Works

A voltage source is connected to a metal comb, creating an electrical potential difference between the comb and the bottom pulley. This potential difference draws a positive charge to the outer surface of the insulating belt. As the motor turns the pulley, the belt carries this positive charge up to another metal comb. The positive charge density naturally moves along the metal comb to the dome, to distribute around the conductor. UBC's Van de Graaff had a large electromagnet at the base for bending the beam of particles to the horizontal, giving the unit a mass spectrometer feature.

The dome of UBC's Van de Graaff accelerator. This piece is now preserved in the stairwell of the Hebb Tower.

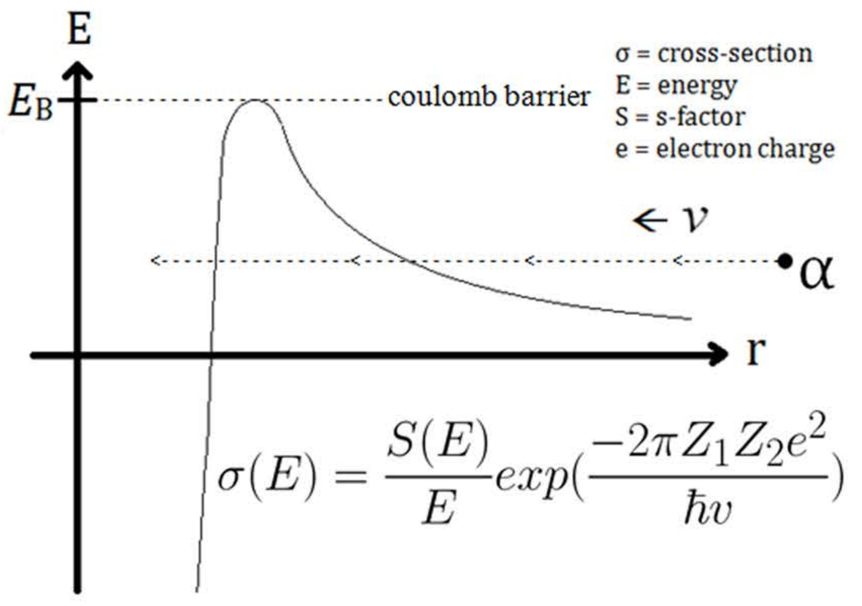
Side view of the Van de Graaff in the south corner of the Hennings building.



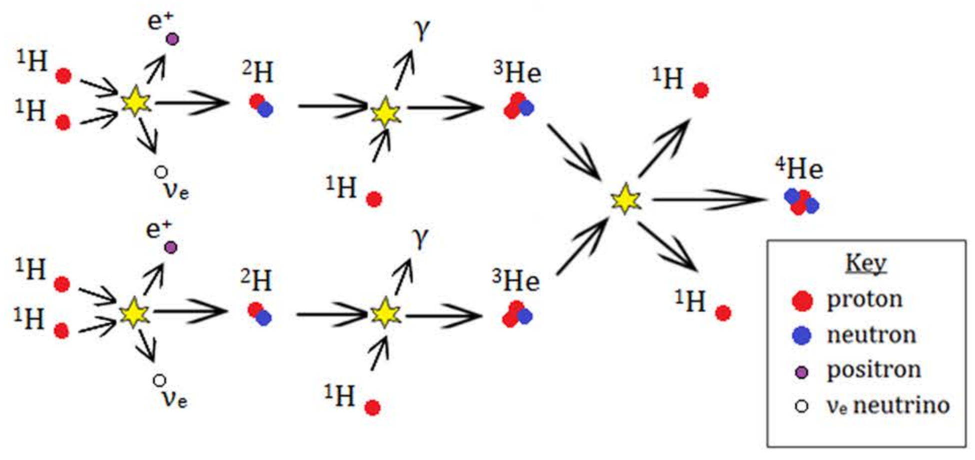

The inner workings of a Van de Graaff Accelerator.

## Hitting the Wall: The Coulomb Barrier

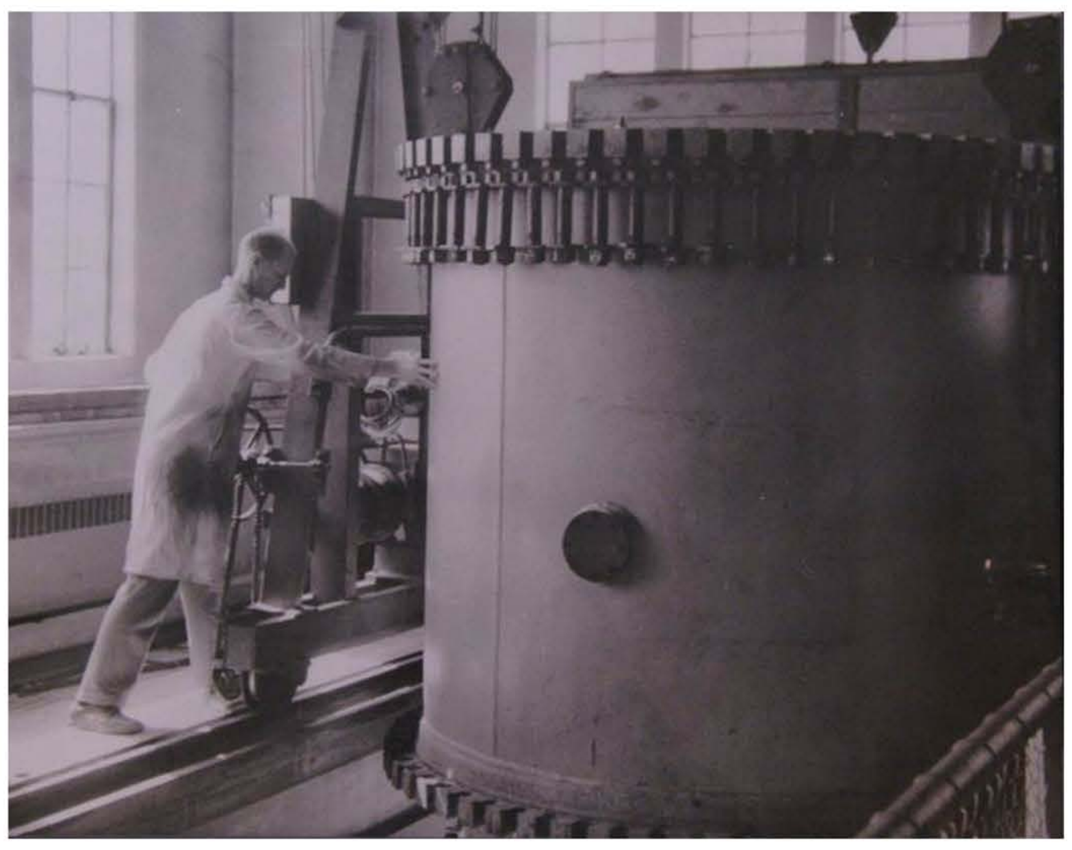
The Sun burns by fusing hydrogen nuclei into helium nuclei (see right). Classical physics requires temperatures of at least 50 MK for this to be possible, given the strong electromagnetic force repelling the protons from each other. This "Coulomb barrier" is proportional to the product of the two charges ($Z_1 e$ and $Z_2 e$), their velocity v and the difficult to calculate energy ($E$)-dependent 'S-factor' - S($E$). How does it happen in the Sun then, with a core temperature of only 15MK? The answer is quantum tunnelling, a rare process with a cross section (σ) so small that it is hard to measure. However, these cross-sections ultimately determine the temperature of the Sun and other stars.




Stellar Nucleosynthesis



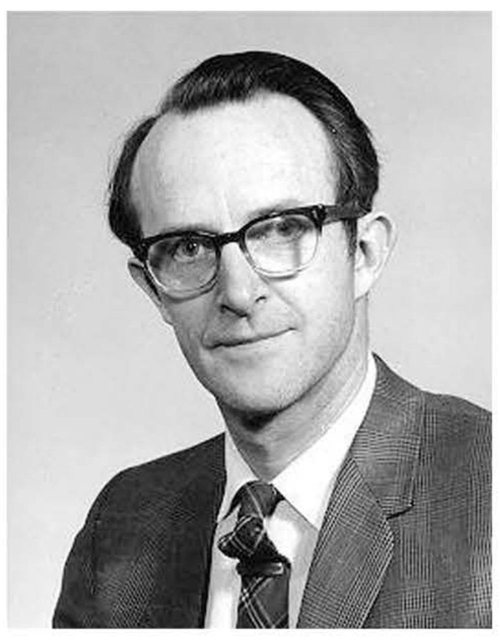

Primary fusion processes in the Sun



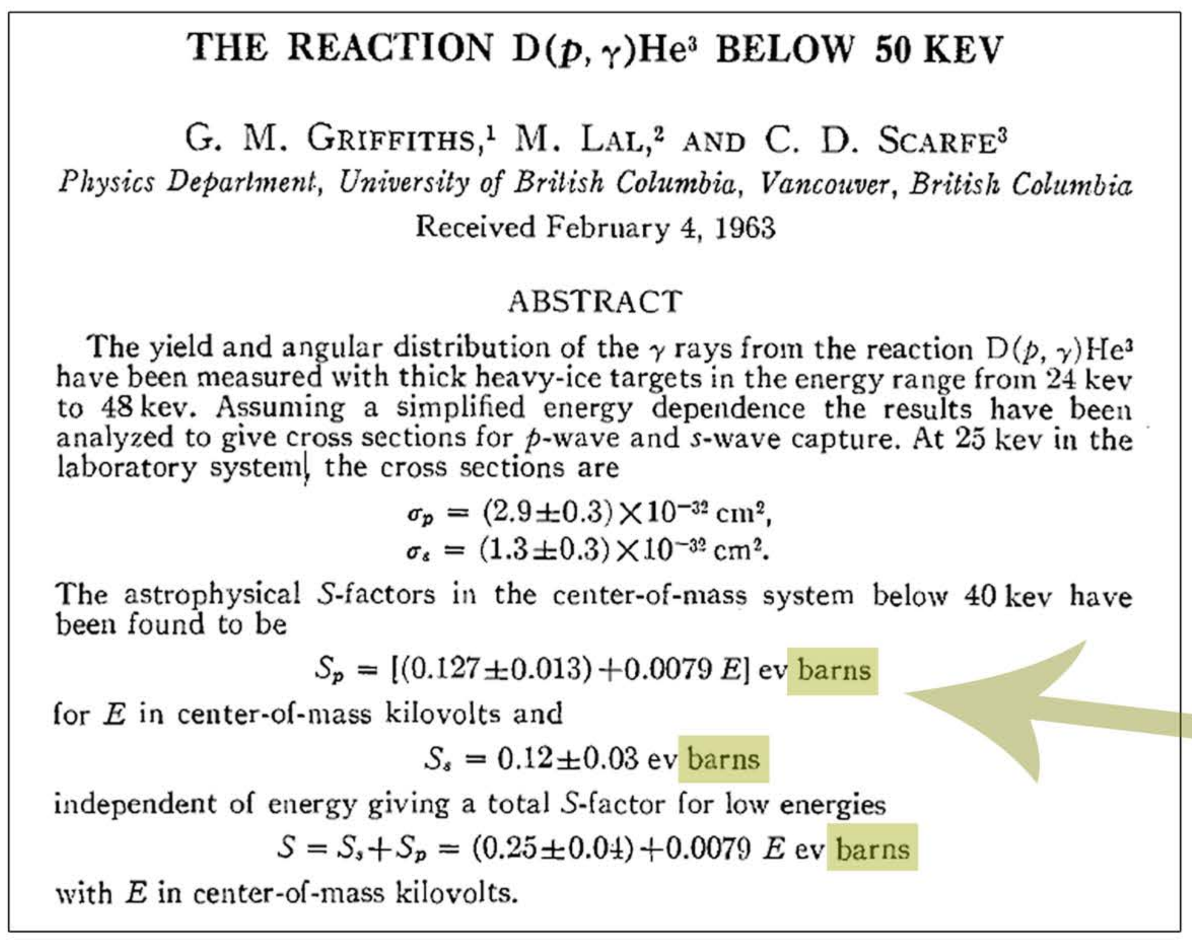
David Lindquist working on the pressure housing of UBC's Van de Graaff accelerator in a room that is now Hennings 318.

## Griffiths' Research

George Griffiths performed research at UBC in determining the 'S-factor' for many basic stellar fusion processes.



Dr. George M. Griffiths in 1969



THE REACTION D($p$, γ)He³ BELOW 50 KEV

G. M. GRIFFITHS,[1] M. LAL,[2] AND C. D. SCARFE[3]

*Physics Department, University of British Columbia, Vancouver, British Columbia*

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ABSTRACT

The yield and angular distribution of the γ rays from the reaction D($p$, γ)He³ have been measured with thick heavy-ice targets in the energy range from 24 kev to 48 kev. Assuming a simplified energy dependence the results have been analyzed to give cross sections for $p$-wave and $s$-wave capture. At 25 kev in the laboratory system, the cross sections are

$$\sigma_p = (2.9 \pm 0.3) \times 10^{-32} \text{ cm}^2,$$
$$\sigma_s = (1.3 \pm 0.3) \times 10^{-32} \text{ cm}^2.$$

The astrophysical $S$-factors in the center-of-mass system below 40 kev have been found to be

$$S_p = [(0.127 \pm 0.013) + 0.0079\, E] \text{ ev barns}$$

for $E$ in center-of-mass kilovolts and

$$S_s = 0.12 \pm 0.03 \text{ ev barns}$$

independent of energy giving a total $S$-factor for low energies

$$S = S_s + S_p = (0.25 \pm 0.04) + 0.0079\, E \text{ ev barns}$$

with $E$ in center-of-mass kilovolts.

**The Barn** - How does a barn have anything to do with nuclear physics? It is a unit ($10^{-28}$ m²) of a nuclear reaction cross-section, which represents the probability of nuclei reacting in a collision. The unit got its name from the size of neutron capture cross-sections, which are enormous (often 1000 barns) compared to the physical size of a nucleus (~ 0.1 barns).

### Spin-off Application

In 1998 UBC graduate student Alan Poon led a team at UBC, the University of Washington, Ontario Hydro Technologies and Queen's University to design, build and deploy a high energy gamma ray calibration source for the then brand-new Sudbury Neutrino Observatory (SNO). The source was a compact 20 keV accelerator and tritium target that produced 20 MeV gamma rays (a thousand-fold gain in energy) with the reaction:

$$p + {}^3H \rightarrow {}^4He + \gamma$$

The entire unit was only 50 cm long and was lowered into the SNO detector to provide calibration for measuring the energy of neutrinos ($\upsilon_e$) produced in solar nuclear reactions. George Griffiths, who had retired in 1989, lent his advice and moral support; he died in 2011.


A.W.P. Poon, R.J. Komar, C.E. Waltham, M.C. Browne, R.G.H. Robertson, N.P. Kherani, and H.B. Mak,
A Compact 3H(p,γ)4 He 19.8-MeV Gamma-Ray Source for Energy Calibration at the Sudbury Neutrino Observatory
Nucl. Instr. Meth. A452, 115 (2000).



Alan Poon's high energy gamma ray calibration source.


Poster prepared by Alex Toews, Alice Lam, Theresa Liao and Chris Waltham
UBC Physics & Astronomy Outreach Program