Toronto Colloquium, Feb. 26, 2004

McLennan, Allen and Misener :

Low temperature physics at Toronto in the period 1920-1936 and the discovery of superfluidity.

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This talk will tell you about three great Canadian physicists who were trained at the University of Toronto and who made major contributions to the discovery of superfluidity in liquid Helium in 1937. Much of the story is unknown or forgotten by the Canadian physics community. Indeed, physicists in other countries often know more about it than we do.

What are my special credentials?

- I have worked on the theory of superfluids for over 30 years. Over this time period , I have talked to and corresponded with many people who were involved in the events I will talk about or knew others who had.

- I met Jack Allen several times at the University of St. Andrews in Scotland and have had the opportunity to examine his personal papers after he died in 2001.

- Even though he was at U of T for most of his career, I never met Don Misener. I have had access to his personal papers thanks to his son Jim Misener, a exploration geophysicist working in Toronto.

John Cunningham McLennan
(1867 - 1935)

Photo taken in Sept. 1920 (by Bassano)

- **Due to difficult family finances, McLennan was 21 when he enrolled at University College in 1888. He took courses from James Loudon, Professor of Physics and President of the University of Toronto. He graduated at the top of his class in 1892 , and appointed assistant demonstrator in physics.**

- **McLennan did research at the Cavendish Lab in Cambridge in the period 1898-1899, under J. J. Thomson. His fellow graduate students included Paul Langevin and Ernest Rutherford. McLennan submitted this research to the new Graduate School at U of T and received his Ph.D. in 1900, the first such degree in the sciences in Canada.**

- **In 1907, McLennan was made head of the Department of Physics, remaining in that position until 1932 when he resigned from the University over an argument about the role of the Graduate School and moved to England.**

In the period 1900-1932, McLennan dominated the Department of Physics :

- **With enormous energy, he built up a research lab that was second to none in North America. Up to 1930s, most of the Ph.D degrees awarded by U of T were to his graduate students.**

- **At the same time, he played a key role in U of T affairs as well as encouraging the Government of Canada to get involved in sponsoring research in Canadian universities.**

- **By all accounts, McLennan "pursued his goals with aggressive and ceaseless determination".**

Catalog No. Lodge E1

Niels Henrik David Bohr, Charles Galton Darwin, Paul Ehrenfest, Ralph Howard Fowler, Hendrick Anthony Kramers, Paul Langevin, Oliver Joseph Lodge, John Cunningham McLennan, Alexander Oliver Rankine, Robert Williams Wood

Date: September 1923

First row L-R: Lodge, Langevin, McLennan, Bohr, F.W. Aston, Ehrenfest. Second row L-R: F.A. Lindemann, D. Coster, Darwin, R.T. Glazenbrook, Wood, Fowler, Kramers, Rankine ; British Association for Advancement of Science meeting ; outdoors ; Liverpool

Credit: AIP Emilio Segrè Visual Archives, Margrethe Bohr Collection

A crucial aspect of McLennan was that he made annual summer visits to research centres in the UK, France and Germany. He found out about the **latest trends in research**, and purchased the latest equipment for the labs at U of T. He kept in contact with the **leading physicists of the period**, arranging their visits to Toronto.

Origins of research on liquid Helium at Toronto

- In 1915, during WWI, McLennan was asked by the Office of the Admirality in London to make a survey of of the availability of Helium gas in the British Empire. The plan was to use it as a safe substitute for Hydrogen gas in military airships.

- McLennan organized teams to do this, making a careful study of all gas wells in Canada and other countries. Ultimately this led to setting up helium gas extraction and purification plants near Hamilton and in Calgary. The Bow Island district wells near Calgary contained 0. 36% Helium gas, the best source found.

- By the end of the war, McLennan had collected 60,000 ft^3 of Helium gas (90% pure), stored near Toronto under pressure in steel cylinders. What to do with it?

- In 1919, McLennan decided to take advantage of his large supply of fairly pure Helium gas, namely to make liquid Helium for research.

- Liquid Helium was first produced in Leiden in 1908, by Kamerlingh Onnes after decades of work. In 1919, it was still the only place in the world that could do this. McLennan asked for assistance from Onnes, who gave Toronto the detailed drawings of the Leiden liquefier and advice. Perhaps the tradeoff was that McLennan arranged for Leiden to obtain a supply of Helium gas. Leiden's source had been stopped because of it's potential use by the military.

April 16 , 1921 - Hydrogen was liquefied at Toronto

Jan. 24 , 1923 - One litre of liquid Helium was produced at U of T, the second lab in the world to do this. This ushered in a decade of pioneering research at Toronto on superfluid Helium and superconductors.

A key person was the graduate student who worked on this project , Gordon Shrum. Later he was the head of Department of Physics at UBC for almost 25 years, as well as the founder and first president of Simon Fraser University.

In his autobiography, published by UBC Press in 1986, Shrum paints a vivid picture of McLennan in the period 1915 - 1925:

“ McLennan was a man with tremendous ambition: a great worker, a marvelous lecturer and altogether a very strong personality”

“ McLennan was the best dressed man on campus, always wearing the most stylish suits”

“ He would rivet you with his great eyes as he talked of physics”

Shrum's undergraduate studies were interrupted by WWI, during which he was in the Canadian Army Artillery. After the War, Shrum completed his degree and took a job in business. While Shrum was visiting friends in the Physics Department in 1920, McLennan asked him to drop in to his office.

Mclennan: " Shrum, during the War, you were in artillery, weren't you?"
Shrum: " Yes "
McLennan: " Shrum, you're not afraid of explosions, are you?"
Shrum: " No "
McLennan: " Shrum, you are just the man I need to help me liquefy Helium!"

McLennan was in a race to liquefy Helium before the National Bureau of Standards (now NIST) in Washington, DC.

McLennan took Shrum with him on a visit to the NBS labs to see how their research was going. While McLennan was talking to the senior NBS physicists upstairs, Shrum was left to talk with the single technician working on the project. The technician observed that " at Toronto, you have the Director of the lab, one graduate student and four technicians trying to liquefy Helium. At the NBS, we've got four senior physicists and one technician. You'll win."
It did, with the NBS lab finally producing liquid Helium in 1926, three years after Toronto.

Prof. Tony Key and me standing in front of **McLennan's family home** facing the Avon river in Stratford, Ontario, right across from the famous Stratford Festival Theatre . Tony is telling me once again that all great Canadian physicists, such as McLennan, have Scottish ancestors.

On the Liquefaction of Hydrogen and Helium
(II Communication)

By PROFESSOR J. C. MCLENNAN, F.R.S., and G. M. SHRUM, M.A.
University of Toronto

I. *Introduction*

In a previous paper[1] by one of the authors, the details were given of an apparatus that had been designed and adapted in the Physical Laboratory of the University of Toronto for the liquefaction of hydrogen. This piece of apparatus proved to be quite satisfactory for preliminary work, but it has since been replaced by another of a somewhat modified design. The operation of a closed cycle for the liquefaction of hydrogen requires considerable experience and knowledge of technique, and in view of this it seemed advisable during the initial stages to construct the apparatus on a unit system. As the work progressed, however, and the preliminary plans made for the construction of a helium liquefier showed that possibly 30 to 40 litres of liquid hydrogen would be required at one time during the operation of the helium liquefaction cycle, the efficiency of the hydrogen liquefier became a matter of prime importance. It was therefore decided to modify the original apparatus and sacrifice simplicity of construction for efficiency in operation.

A second apparatus was consequently constructed. It has been thoroughly tested and has fulfilled all the exacting demands made upon it. A description of the apparatus and the method of operating it is given in Section IV.

The work on the design and construction of the equipment constituting the cycle for the purification and liquefaction of helium has also been completed, but an unfortunate delay in the delivery of suitable vacuum flasks makes it impossible at present to report a successful operation of this equipment. In Section VII there is given the details of the apparatus and the method we propose to follow in using it.

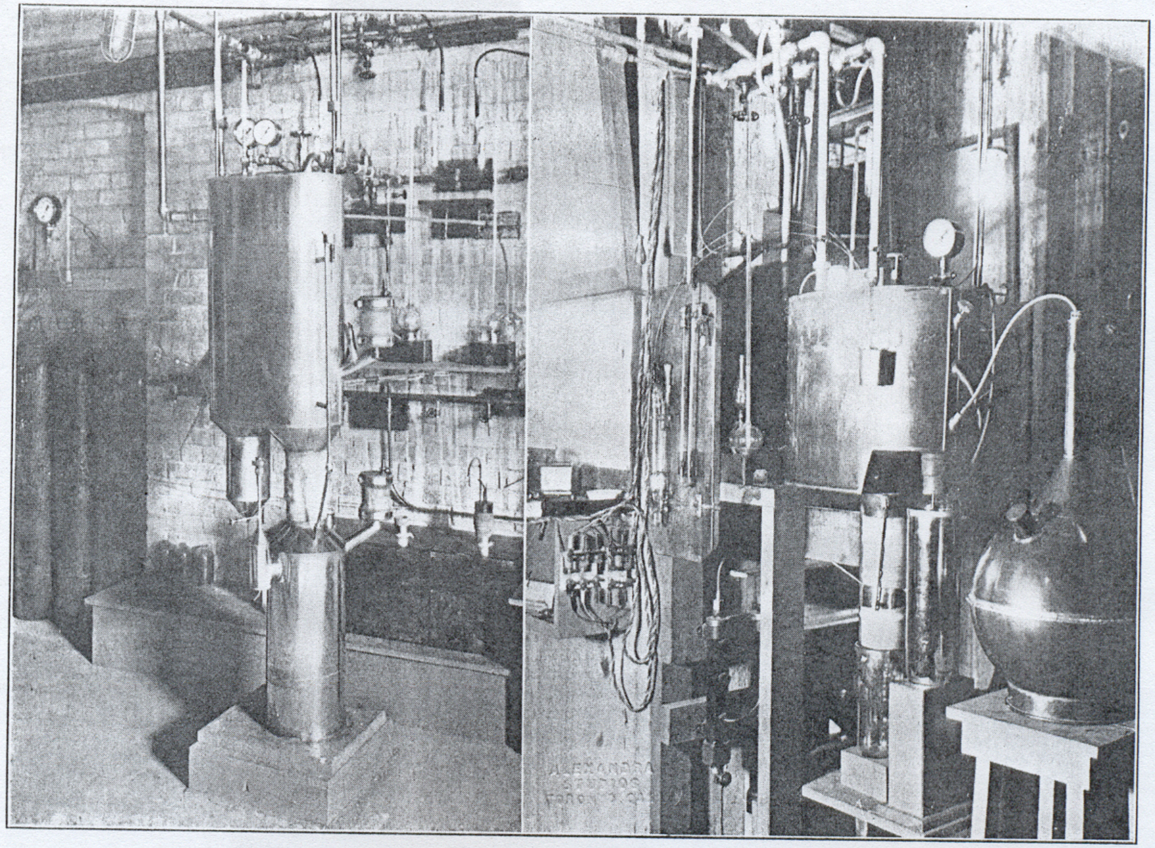
II. *Compressors and Gasometers*

The hydrogen is compressed by means of a specially designed four-stage belt-driven compressor (see Fig. 1, also Plate I, 1) built by the Burckhardt Engineering Works of Basle, Switzerland. The cylinders are water-cooled, have a forced oil lubrication and are fitted

[1]McLennan, Trans. Roy. Soc. of Canada, May, 1921.

Paper by McLennan and Shrum, ***Transactions of the Royal Society of Canada***, 1922

PLATE I



"a" "b"

Helium liquefier at the University of Toronto

McLennan and Shrum, Transactions of the R.S.C.,1923.

From the PHILOSOPHICAL MAGAZINE, Ser. 7, vol. xiv. p. 161, *July* 1932.

The Scattering of Light by Liquid Helium. By Prof. J. C. MCLENNAN, *F.R.S.*, H. D. SMITH, *M.A.**, *and* J. O. WILHELM, *M.A.*

[Plates IV. & V.]

Introduction.

AMONG the many interesting features encountered in the study of liquid helium is the existence of two distinct liquid states. This was first suggested by Keesom and Wolfke ‡ in 1927. They found that at 2·19° K. there is a triple point, at which temperature the two liquid phases exist together in equilibrium with the helium gas. One phase, stable at temperatures above the point, is designated liq. He I, and the other, stable at temperatures below, is known as liq. He II. The physical properties of the two liquids differ materially, and sudden changes in the values of the density, dielectric constant, specific heat, heat of vaporization, and surface tension, occur at the triple point. Abrupt changes of this nature are usually accompanied by molecular phenomena of some sort, such as an association of molecules, or a change in molecular structure. In order to investigate the possibility of the occurrence of molecular changes which might explain the observed phenomena, we carried out experiments in an endeavour to obtain the Raman spectra of liq. He I and liq. He II. A study was made also of the Rayleigh scattering of the two phases, especially in the neighbourhood of the transition point, and the intensity of the Rayleigh scattering at this point compared with that of benzene at room temperatures.

Apparatus.

The essential parts of the apparatus used in these experiments are exhibited in fig. 1. The liquid helium was siphoned over the liquefier into the Raman tube, A, until a column of clear liquid, about 30 cm. in height, was obtained. In order to preserve the liquid helium the inner Dewar flask was surrounded by a second Dewar flask B, containing liquid air. The top T, made of German silver, was fastened to the Raman flask by a rubber joint at the point C.

* Fellow of the National Research Council of Canada.
‡ Keesom and Wolfke, *Leiden Comm.* No. 190 *b*.

McLennan is given credit for the **first explicit observation** that superfluid Helium behaves in a very strange manner. In this 1932 paper on the scattering of light, he notes that the **rapid bubbling** which occurs as one approaches the transition **abruptly disappears** at T_c .

Photo taken around 1950

John Frank (Jack) Allen

(1908-2001)

Austin Donald Misener

(1911-1996)

(at Cambridge, 1937)

Photo is the property of Jim Misener.

Allen and Misener were graduate students who were educated in the thriving low temperature group that had been built up at the University of Toronto by 1930.

Jack Allen

- **Born in Winnipeg in 1908, his father was the first head of the new Department of Physics at the University of Manitoba.**
- **In 1929, Allen started his Ph.D. studies at U of T under McLennan, finishing in 1933. As a graduate student, he published 10 papers on superconductors and their alloys.**

- **Allen was a very independent-minded, take-charge sort of person, and the fact that McLennan was busy on other things (resigning in 1932) suited Allen fine.**

- **Allen applied to go to Cambridge in 1934 to work with Peter Kapitza, who had just constructed a new kind of Helium liquefier and produced the first liquid Helium at Cambridge. By the time Allen got there in the fall of 1935, Kapitza was under house arrest in the Soviet Union with instructions to build up a new low temperature lab in Moscow. This became the famous Institute for Physical Problems.**

Cavendish Laboratory,
Cambridge.

19th August 1935.

Dear Mr Allen,

I have received your letter enquiring whether there is a possibility of obtaining work in the Royal Society Mond Laboratory, and Sir John McLenn has also written to me about you.

You may have heard that in the absence of Professo Kapitza I am provisionally Director of the Mond Labora and Dr Cockcroft is second in command. The Royal Soci have given permission to appoint two Fellows at £400 a year each, to help in the work of the Laboratory. One of these will be on the theoretical side, and an appoi ment is likely to be made soon. For various reasons, are not in a position to fill the other post for some little time. I would naturally take your claims into consideration in selecting the new Fellow, but I shoul mention there are several potential candidates in the Cavendish Laboratory. Under these conditions, I am pr pared to offer you an opportunity of carrying on your investigations in the Mond Laboratory, beginning early in October. This will give us an opportunity to see something of you personally before the final appointme is made. As you can quite appreciate, I cannot at thi stage make any definite proposal. If you decide to com to work in the Laboratory, the exact nature of your research will be a subject of discussion on your arrival. I am not at all sure whether the research you suggest is the one we should like you to undertake.

Dr Cockcroft will be in Cambridge from September 24th onwards, and if you come to Cambridge early you could get in touch with him and discuss matters with him. I shall not myself return to the Laboratory until the first week in October.

We shall be very glad to welcome you to the Laboratory and to offer you good opportunities for carrying on your investigations. Apart from the proposed Fellowships, there are no funds available to support research in the Mond Laboratory, but if necessity required it, there may be an opportunity of adding to your resources

- 2 -

by helping with demonstrations or work of a supervisory character.

Would you please write to me direct at :

Chantry Cottage,
Chute,
Nr. Andover,
HANTS.

where I am spending my vacation.

Yours sincerely,

Rutherford

Letter to Allen about a research position, from **Rutherford**. Note the reference to McLennan at the start.

From personal papers of J.F. Allen.

- **Entering this vacuum at the Mond laboratory, with Cockcroft as the acting Director to replace Kapitza, Allen quickly took over the work using liquid Helium. After a few months, he was even paid a salary. Allen later commented that physics research at Cambridge at that time was like a "civilized jungle". He thrived!**

- **Allen measured the flow of heat in superfluid Helium in thin capillaries.This paper (Allen, Peierls and Uddin, Nature, 1937) showed that the thermal conductivity of superfluids was large and strange. It had a big impact.**

Mond Lab staff, 1938

Donald Misener

- Misener's family were United Empire Loyalists who moved to Ontario in 1785. Don was born in Toronto but brought up in Kobe , Japan by his mother , who was a missionary and distinguished educator. Misener was fluent in Japanese.

- He entered U of T in 1929 and graduated in 1933 with the silver medal for mathematics and physics. His first wife, Agnes Crutcher, got the gold medal in the same year in math and physics!

- He did his M.Sc. in 1933 - 36 at U of T, working on superconducting thin films as well as liquid Helium.

First evidence for superfluidity

- Misener carried out a seminal experiment in 1935, measuring the shear viscosity of liquid Helium just below the transition temperature T_λ=2.18 K from the decay of the torsional oscillations of a rotating cylinder.

- Misener found that the viscosity decreased sharply as one went just below T_{λ}.. The article in Nature made a big impact on the low temperature community.

- However , it was published under the sole name of E.F Burton, the new Head of the Department. Burton had been a long-time colleague of McLennan (who had abruptly resigned in 1932 in an argument with U of T).

- **Burton did give complete credit to Misener for doing the experiment in the acknowledgements. Later in 1935, a longer paper was published by Wilhelm, Misener and Clark (these other people were senior technicians in the cryogenics lab at Toronto).**

- **However, Burton being the sole author of the first paper was unfortunate in view of later controversies about who should get credit for the discovery of superfluidity.**

It became clear by the 1960s that Misener had measured the decrease in the **normal fluid density**, rather than the viscosity. In fact, this is a more **fundamental signature** of superfluidity.

Allen and Misener join forces in Cambridge

- Don Misener went to Cambridge to do his Ph.D. in the period 1936 -1938. He quickly started to work with Allen, studying the viscosity of superfluid Helium flowing in thin glass capillaries. A and M found that the flowing superfluid showed no viscosity.

- Their work was published as a letter in Nature on Jan. 8 , 1938 , back to back with a paper by Kapitza announcing the same sort of results.

- These short papers marked the beginning of the study of quantum fluids. We now know that superfluidity is a macroscopic quantum effect due to BEC.

Cavendish and Mond Laboratories, 1936

Who discovered superfluidity in liquid Helium?

While the low temperature community has generally given equal credit to both Kapitza and Allen and Misener for the discovery, there has been a tendency in the larger world to give Kapitza priority. Indeed, Kapitza was awarded the Nobel Prize in Physics in 1978 for his work, with almost nothing said about Allen and Misener. The famous Landau School never makes any reference to A and M.

I have worked out the detailed chronology of events, based on new information from the private papers of both Allen and Misener. Almost all accounts in the literature give a slightly incorrect version of one or more of these facts.

1937 Nov.11 ------ first viscosity experiment by AM.
Nov.24 ------ discovery of no-viscous flow by AM.
Dec. 3 -------*Nature* receives paper by Kapitza.
Dec.17 -------W.L.Webster (another Canadian) brings news from Moscow and Kapitza's results and asks Cockcroft to check the proofs of Kapitza.
Dec. 21 ------ AM submit their paper to *Nature*. Received next day. Cockcroft says to send proofs to Allen's apartment in Cambridge.
Dec. 25 ------ Cockcroft (away on Christmas) sends letter to Kapitza that he has corrected the proofs and sent them back to the editor. He tells Kapitza about the results of AM.

1938 Jan. 8 ---------Both papers are published in ***Nature*.**
Jan.12 --------Allen discovers the **fountain effect.**

THE ROYAL SOCIETY MOND LABORATORY
UNIVERSITY OF CAMBRIDGE

Tel. 4655

Free School Lane
Cambridge

18th December, 1937

Prof. Kapitza,
Institute for Physical Problems,
MOSCOW.

My dear Peter,

I am sending you herewith a copy of a letter to Laurmann about his leave of absence. So far as I am concerned you know that if Laurmann wishes to stay with you, we, on our part, should raise no objections. Since he has been your assistant for so long, he is naturally more valuable to you than to anyone else, and must be very difficult to replace.

During the last few weeks, we have been working on the viscosity of liquid helium by measuring the flow through capillary tubes having diameters down to 1/50 mm. We have found it impossible to produce laminar flow, and that the viscosity is less than 10^{-9}. We do not get a [illegible] law & there are many curious things which may mean the theory of ordinary liquid flow is not applicable.

Yesterday, just as these experiments were being completed, Webster came in and told us that you also had been doing similar work, and we were interested to find that you had got similar results.

We had been led to do this by many difficulties in the experiments on the heat conductivity. In particular, for temperatures of about 1.1° the vapour pressure above the liquid in the small bulb appears to drop rather than rise on applying heat.

Webster asked me to see your proofs through the Press, since he is going away to France, and this I shall be glad to do. We shall be sending in a letter to "Nature" this week-end.

With kind regards to all,

Yours sincerely,

John Cockcroft

Letter from Cockcroft to Kapitza on Dec.18, comparing the very similar results. He says they (AM) were just writing up their own paper.

Correspondence re the first observation of superfluidity. Letter by J.D. Cockcroft.

JFA 23-11-77

21st December, 1937.

The Editor of "Nature",
St. Martin's Street,
LONDON. W.C.2.

Dear Sir Richard,

I am sending you herewith a note which I hope may be possible to publish in an early issue of "Nature." It concerns a further study of the extremely interesting properties of liquid helium II. Just as this work was completed we received word that Kapitza had also been attacking this problem with very similar results, and that he had communicated his results to "Nature". I was asked to see his proofs through the Press and I should be glad if you co ld forward them to me at the following address :-

Stansfield Hall,
Todmorden,
Lancs.

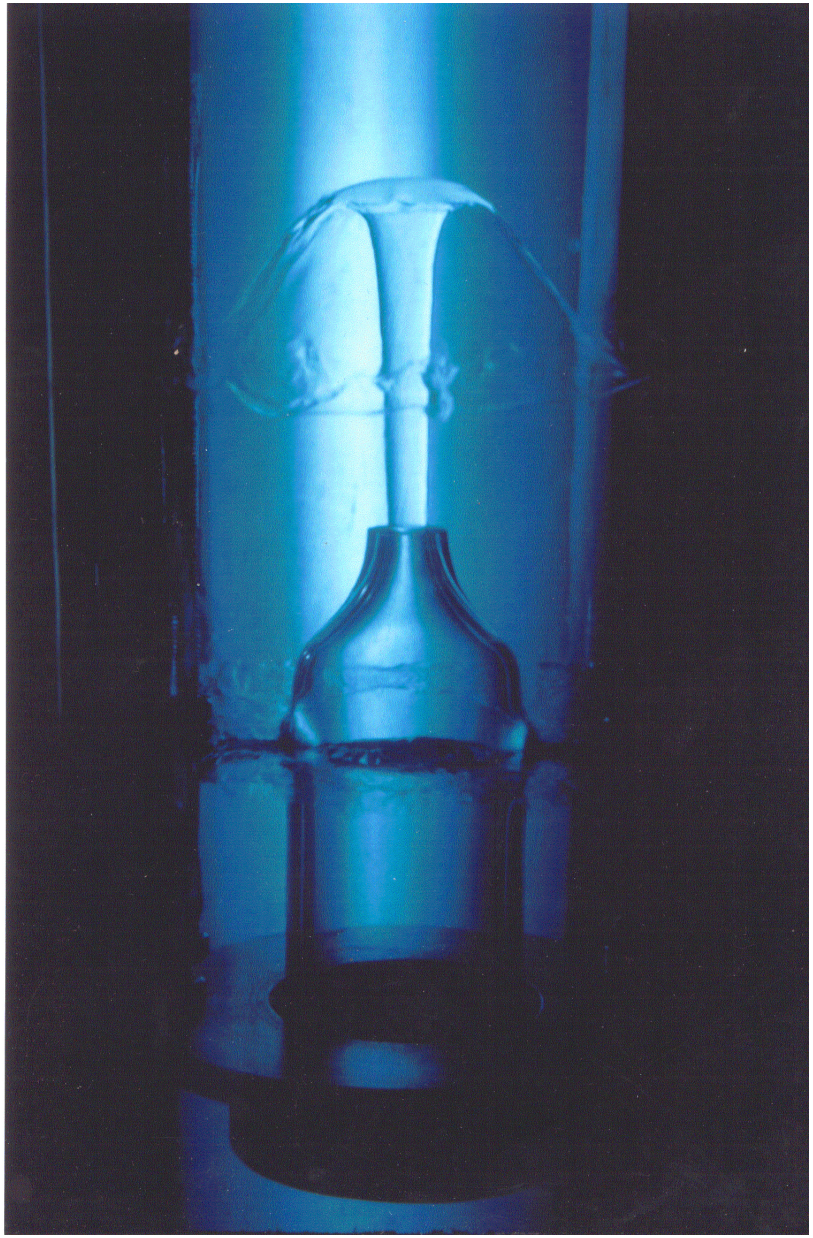
where I shall be staying until January 3rd. The proofs for the Allen-Misener paper should be sent to :-

J. F. Allen,
400, Milton Road,
Cambridge.

Letter to Nature on Dec.21 from Cockcroft, submitting the AM paper and saying that he has been asked to check the proofs of Kapitza’s paper.

Log of the Helium runs made by Misener, from his 1851 Exhibition Scholarship Reports of 1937 and 1938

23/IX	37	Sn X Sn XI	Current Effects	III	Transverse field. Large thermal eff	
13/X	38	Sn XII Sn XIII	Current Effect	III	Transverse field -	
22/X	39	Sn XII Sn XIII	Current Effects	III	Transverse field.	
27/X	40	Sn XIV Sn XV	Current Effects	III	Transverse field.	
29/X	41	Sn XIV Sn XV	Current Effects	III	Longitudinal Field	
4/XI	42	Sn XVII Sn XVII	Current Effects	III	Longitudinal Field	
5/XI	43	Sn XVI	Current Effects.	III	Longitudinal Field	
11/XI	44	S.C. 1	Viscosity & ~~Surface Ten.~~	VII	Flow not viscous	⇐
17/XI	45	S.C. 2	Viscosity	VII	Capillary too large.	
10/XI	46	Sn XVII Sn XVIII	Current Effects {Threshold Field	III IV	Longitudinal Field	
19/XI	47	Sn XIX Sn V	{Current Effects	III	Longitudinal Field Long capillary - non-viscous flow	⇐
24/XI	48	S.T. 1	Viscosity & Surface Ten.	VII VIII		
1/XII	49	S.T. 2, 3, 4.	Surface Ten.	VIII	Preliminary, to see if jump at λ point.	
3/XII	50	S.T. 2, ~~3,4~~	Surface Ten.	VIII	Accurate determination. Data published.	
15/XII	51	Sn XX	Resistance	I	Measurement of successive 1 cm. sections.	
17/XII	52	S.C. 3	Viscosity	VII	Thermometer tubing	
(1938) 12/I	53	P.T. 1	Viscosity	VII	Discovery of Helium Fountain	⇐
14/I	54	P.T. 2	Viscosity	VII	Tube packed with 4F Carborundum	



The famous fountain effect in superfluid Helium, discovered by Allen on Jan. 12, 1938.

This photo is from a classic movie about superfluidity made by Allen(the 5th edition was completed in 1982). Photographing liquid Helium is tricky since it is more or less invisible!

What do we learn from all this?

1. A and M discovered superfluid flow quite **independently** from Kapitza.

2. A and M paper was much **more detailed and quantitative** than Kapitza's was.

3. Kapitza's work was clearly **inspired by the earlier work** at Toronto and Cambridge. He only has three references, all to papers involving work by **Misener** (1935) and **Allen**(1937).

Why did only Kapitza get the Nobel Prize?

1. Allen had gone to Cambridge to work with Kapitza and used Kapitza's liquefier in his research. He was like a postdoc in Kapitza's group.

- Allen came from Toronto as a **fully independent** researcher, and was more experienced with working at low temperatures than Kapitza.

- Allen was put into a **vacuum** at the Mond laboratory with Kapitza absent, and effectively took over the direction of the group using liquid Helium for research.

- Cambridge was **very generous** to Kapitza(a protégé of Rutherford). Two key technicians were sent to Moscow for **two years**, and all kinds of cryogenic equipment was shipped there as well. Kapitza was **helped** to get a lab going in Moscow very quickly. Allen had to scrounge around at the Mond Lab.

2. Kapitza submitted his paper 2 weeks before Allen and Misener did, and the latter saw a copy of Kapitza's results

- There is no evidence that Allen ever saw Kapitza's paper. Cockcroft did because he was asked to check the proofs by Kapitza. He did this away on Christmas vacation.

3. The sudden death of McLennan in 1935 in Europe

- McLennan would have been a **tiger** promoting his former graduate students from Toronto. Burton had no clout on the international stage. There is **no evidence** that U of T ever tried to push Allen's work.

- Kapitza had been a protege **Rutherford** and was a close friend many important Cambridge physicists. They would not have pushed the claims of Allen and Misener for **equal priority**. Allen, always a proud man, was left to **defend his own case.**

4. Kapitza let the Nobel Prize Committee know that he would not share the prize with Allen.

- I have heard this "rumor' from several people, and **David Shoenberg** has confirmed to me (2002) that a Russian physicist he knows has heard the the same thing.

- Kapitza's Nobel prize talk is very unique. It does not **say a single word** about the discovery of superfluidity. It is about his much later work on hot plasmas! He says not a word about Allen and Misener.

- It gives a reasonable explanation why it took **40 years** before a Nobel prize was given for the discovery of superfluidity. This phenomenon is at basis of much of modern condensed matter physics, and is one of the **most dramatic examples of quantum mechanics in the visible world.** Why did it take so long?

After WWII, **Allen** accepted a **professorship at the University of St. Andrews in Scotland.** He built up a low temperature group there and stayed active in organizing international conferences, etc. I visited him in his later years, and one could see that he was very attached to his time at U of T.

Misener returned to U of T in 1939. After the war, his interests shifted to geophysics and the science-government interface. He played a key role in **creating the CAP** in the period 1945-50. He was the first Director of the Institute for Environmental Studies at U of T.


(1908–2001)

Co-discoverer of superfluidity