<u>Al and me; our joint research program.</u>

Hughie Young

Al and I began our collaboration at the Oak Ridge National Laboratory in 1963 and this continued until our effective retirements 25 years later (our last joint publication being in 1988). In total, we published 32 research papers (sometimes jointly with others) in journals of international standing and these are listed below. The journals mentioned are all of high international standing; for example, Phys.Rev (Physical Review) is the leading US physics journal. Moreover, Phys. Rev. Letters, of which the list shows two entries (4 and 14), is often said to be the most prestigious physics outlet of its kind in the world. Most physicists do not achieve a publication there throughout their careers.

After two years together at Oak Ridge, I returned to England (Sheffield University 1966-71, University of East Anglia, Norwich 1971- 88) and Al moved on to Northern Illinois University for the rest of his career. From then onwards it was a matter of supplementing our correspondence with many visits back and forth across the Atlantic. Sylvia, who keeps better records than I do, has shown me a list of 7 summer visits by Al to Norwich during my 17 years at UEA and he had visited Sheffield on several occasions (details now forgotten) before that. Then, in the other direction, I spent the first 6 months of 1970 on leave with Al in DeKalb and, in 1975, he and I met for a summer of work with Malcolm Stott at Queen's University in Canada. On several of these visits (including all the longer ones), our families accompanied us and the great friendship forged in Oak Ridge continued unabated.

Our joint scientific work was largely but not exclusively on the theory of liquid metals. To explain why this was so, I need to note that in basic physics, there comes a time when a problem is ripe for development because enough experimental data have accrued and the developing theory is in good enough shape to (perhaps!) provide an explanation. And so a comprehensive step forward might be achieved by an effort by many groups spread around the world. This was how the problem of liquid metals was perceived in the early 1960s and by the 1990s the required insight had, in this way, been largely achieved. Liquid metals are no longer profoundly mysterious and Al played his part in achieving this goal. You will see in the list below reference to the various experimental phenomena needing explanation – resistivities, thermopowers, X-ray and neutron scattering data, crystal structures and compressibilities, Fermi surfaces, Knight shifts etc. These were explained using such theoretical tools as pseudopotentials, pseudo-atom phase shifts, density functionals and classical and quantum mechanics. In the end, Al played his part in obtaining a grand solution of the type I have indicated above.

I will single out three features of our joint career for especial mention:
(i) We had discovered an important theoretical concept (the phase shift) while together in Oak Ridge during 1963-5 and this needed the publicity of announcing it at the forthcoming important and influential conference to be held at Brookhaven in 1967. This was the First International Conference on Liquid Metals – a series, now embracing also amorphous solids, that continues to this day (the 13$^{th}$ having been held in Ekaterinburg, Russia, in 2007). Al took on the responsibility of presenting our joint work at this seminal

conference and he did the job with great expertise. The Proceedings were published in Advances in Physics; see ref.9 below and left a lasting favourable impression.
(ii) Our phase shift method allowed us to solve a longstanding baffling puzzle. There have been many such small triumphs but I think I can explain this one fairly simply in layman's terms. We learn about thermoelectricity at school (thermocouples etc.) and it is based on the following phenomenon. If you heat one end of a metal bar and cool the other, an electrical current flows from the hot to cold end. This is because 'hot' electrons migrate to the colder end easier than 'cold' electrons migrate to the hotter. All metals behave in this way – copper, tin, iron, aluminium, sodium, zinc, etc. etc. – *except* lithium. Why is lithium different? Al and I found the answer: electrons bump into stationary atoms as they migrate (rather like ball-bearings on a pinball table). But we found that in lithium the 'hot' electrons see dramatically enlarged atomic cross sections – so enlarged they form an effective barrier to migration. But the 'cold' ones, being unaffected, can flow to the other end. When we published this work (ref.13) almost simultaneously there appeared an essentially equivalent paper by John Robinson of the Argonne Lab. He'd been working on the same problem so near geographically! For a while, he, Al and I were the only people in the world who knew why nature behaved in this strange way.
(iii) In and around the year 1970, Al supervised, at NIU, a Nigerian graduate student called Ibrahim Umar. I met Ibrahim during my 1970 visit to DeKalb and, when he had completed his M.S. studies, Al sent him for Ph.D. work in Norwich. We were both very impressed by Ibrahim who eventually went home to become a Vice-Chancellor of his University (Bayero). And that was only the beginning of a career that will have brought great benefit to many inside and outside Nigeria. For example, he helped draft the Constitution of the Second Republic of Nigeria and has had input into the International Atomic Energy Authority. His excellent qualities – scientific and personal - were recognised early on by Al and Al's excellent qualities have no doubt helped to shape Ibrahim's career and also his general views and attitudes.

This account is intended as a factual account of Al's scientific collaboration with me. But I cannot end without adding a personal note. His effect on me, in a general sense, has been profound. He taught me so much: his United Nations study group showed me clearly the necessity for international collaboration and some of the ways of achieving it, his getting me out to 'march on the freedom line' taught me about the prevalence of racial prejudice and the need to combat it, and his Unitarian Church activities and vigils have heightened my awareness of, for example, repression in poorer countries around the world. His high minded morality and his personal friendship have meant so very much to me. Al, my great and good friend, thank you so much.

<u>Al's publications with me and sometimes others</u>

1 Electrical Resistivity of Metallic Lithium vapour. Phys.Rev.138, A 1591 (1965)
2 Pseudopotential Theory of Metallic Lithium. Phys.Rev. 139, A401 (1965)
3 Long-Range Interatomic Forces in Metallic Lithium. Phys.Letters18, 10 (1965)
4 Alkali Impurity Resistivities in Liquid Sodium. Phys.Rev.Letters 16, 727 (1966)
5 Electrical Resistivities and Thermoelectric Powers of the Monovalent Liquid Metals. Phys.Rev.160, 482 (1967)

6 Monovalent Impurity Resistivities in Monovalent Metals. Phys.Rev. 160, 490 (1967)
7 Pseudo-Atom Phase Shifts for Monovalent Metals and Alloys. Proc.Phys.Soc. 92, 446 (1967)
8 Resistivities and Thermopowers of the Alkalis under Pressure. Proc.Phys.Soc92, 460 (1967)
9 Pseudo-Atom Phase Shifts of Liquid Metals and Alloys. Advan. Phys. 16, 581 (1967)
10 Thermoelectric Powers of Alloys of Alkalis in Alkalis. Phys.Rev. 166, 746 (1968)
11 Interatomic Potentials in Monovalent Metals. J. Phys. C 1, 486 (1968)
12 Distribution of Electron States in Monovalent Metals. Phil.Mag.18, 895 (1968)
13 Thermoelectricity and Energy-Dependent Psuedopotentials. Phys.Rev.184, 1003 (1969)
14 Pseudopotentials, Muffin Tins and Fermi Surface Anisotropies Phys.Rev.Letters 23, 973 (1969).
15 Alkali Solute Knight Shifts in alkali matrices. J.Phys.C 3, 40 (1970)
16 Pseudopotentials and the Thomas-Fermi method for metals. J. Phys. C3, S347-53 (1970)
17 Knight Shifts of the alkali metals. 3rd Mat. Sci. Res Symp.(NBS publication p651) (1971)
18 Pseudopotentials and residual resistivities in Silver and Gold. Phil.Mag.23, 977 (1971)
19 Lattice spacings and compressibilities versus Pauling radii and valencies. Phys. Rev.B4, 3287 (1971)
20 The shielding of an ion by an electron gas. J.Phys.F 3, 1381 (1973)
21 Crystal potentials and APW and KKRZ pseudopotentials. J. Phys.F 4, 394 (1974)
22 Thermodynamic calculations for liquid alloys with an application to Na-K. J.Phys. F 4. 1691 (1974)
23 Vacancy formation energies and Faber's formula. J. Phys. F 4, 2117 (1974)
24 Densities of electron states in liquid transition metals. Phil.Mag.33, 381 (1976)
25 The von Weizsacker coefficient in density functional theory. Z. Narurforsch. 31a, 898 (1976)
26 Ab initio thermodynamic calculations for liquid alloys. Phil.Mag.35, 1012 (1977)
27 A simplified WCA theory of liquid structure. Chem. Phys.19, 147 (1980)
28 Soft sphere characterisation from liquid structure facors: application to lead. Phys.Chem.Liq.10, 279 (1981)
29 Core sizes and forces as deduced from observed liquid structure factors. J.Non-Cryst.Solids 61&62, 219 (1984)
30 Interatomic core forces deduced from observed liquid structure factors. Phys.Chem.Liq.13, 293 (1984)
31 The signature of long range interatomic forces in observed liquid structure factors. Phys.Chem.Liq. 14, 1 (1984)
32 Soft core description of the structure factor of liquid 3d transition metals. Zeits. Fur Phys. Chemie Neue Folge 156, 519 (1988)