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Blurring the boundaries among astronomy, chemistry, and physics: the Moseley centenary

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Abstract. The year 2013 marks the 100th anniversary of the first of two brief papers by Henry Moseley (1889−1915) in which he provided laboratory evidence that atomic number (Z, the charge on a nucleus) was more fundamental than atomic weight (the total number of particles, A, in a nucleus). He had been trained as a physicist; the most immediate impact was on chemistry (though physics eventually took over much of the territory); and the sorting out of the two concepts provided the foundation on which the modern understanding of nucleosynthesis in stars could be built.

This discussion is a very preliminary one, drawing items from a disparate collection of secondary and tertiary sources. Additions, subtractions, and corrections from readers would be most welcome. The sections that follow provide "snapshots" of the status of astronomy, chemistry, and physics in 1863, 1913, 1963, and 2013, with sporadic mentions of one field contributing to another, invading another, or taking over parts of another. The last section focuses on more of the overlaps. If there is a lesson, it is that the fraternizers are more likely to be remembered than the isolationists, though this is at least partly a "history is written by the winners" effect.

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1. Introduction

Scientists, like other human beings, are territorial creatures, not just about our parking spaces and seats in the colloquium room but also about our scientific territories from the narrowest thesis topic ("Who's been looking at my nebula and left dust all over it?") to the whole of physics, chemistry, or astronomy. Thus many astronomers objected to spectroscopes invading their observatories in the 1860s; chemists resented Moseley's use of X-rays in 1913 to supplement their

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retorts and test tubes in identifying elements; and physicists typically disbelieve astronomers who suggest new physics on the basis of astronomical data. Three other combinations are possible. These are chemistry invading physics, physics invading astronomy, and astronomy invading chemistry.

The game plan here will be, first, to try to map out the three territories at representative times (1863, 1913, 1963, and 2013) and then to explore some of the overlaps and transgressions, both successful and unsuccessful. History is, of course, written largely by the winners, and I suspect there were many other unsuccessful attempts at interdisciplinarity over the years that have left no traces in standard history books. Two quick examples to clarify what is meant: astronomers were successful when they told physicists that a deficit in neutrinos coming from the Sun resulted from incomplete theory of the weak interaction, and unsuccessful when they (a different group) tried to tell physicists that there must be a fourth cause of redshifts in addition to gravitation, Doppler effect, and expansion of the Universe, requiring some kind of new physics. These both belong to the period 1963 to 2013.

This is the Moseley centenary not because of his birth or death, but because 1913 saw the publication of the first of two brief papers in which he established that atomic number (number of positive charges on a nucleus) rather than atomic weight (mass of a nucleus) was the superior number for ordering the elements in a periodic table. At the time of his death, he had looked at 44 elements (all those from Al to Au that could be prepared in suitable from). The method was to make plates of a substance, fire a beam of electrons at it, and measure the energies of the X-rays emitted when electrons kicked out fell back into the N = 1 shell. The quickest way to persuade yourself that those energies will scale as Z^2 is to look back at a derivation of Bohr orbits. He quite properly credited earlier and contemporary work by Charles Barkla, Anton van den Broek, and Bohr (Scerri 2007). And soon after Moseley's death, cleaner, more extensive plots were produced by the Braggs (Moore 1918).

Moseley's own contributions included sorting out the rare earths, putting paid to nebulium and coronium as light elements many years before improved understanding of atomic structure led to correct identification of the ionization states and transitions actually responsible for the lines credited to Nb and Cn; and putting Prout's (1815) hypothesis on a firm foundation, ready for the astronomical structure Cameron (1957) and Burbidge, Burbidge, Fowler & Hoyle (1957) would eventually erect there (Scerri 2007). Prout's hypothesis was that all other atoms were made up of sums of hydrogen atoms.

Two years later, Henry Moseley was dead at Gallipoli, having forcefully insisted on being commissioned in the British armed forces. As early as a 1935 conference (Gamow 1935) the predecessors of B^2FH were asking whether the infant discipline should be called nuclear physics or nuclear chemistry. Both now exist, as divisions of the American Physical Society and the American Chemical Society. They don't mean the same thing, and only the APS version has a significant boundary with astronomy.

In case you haven't already noticed, this discussion throughout has a significant American bias, both because those are the communities I know best (though some similar things can be said about IUPAP and the IAU as about APS and AAS) and because those are the books most often piled in my office, home, and sometimes nearby offices and homes!

Here are three additional preliminary thoughts. First, 2013 is also the centenary of the Bohr atom, which (in the eyes of extreme reductionists) began the process of reducing chemistry to physics. Second, people do sometimes change their minds. Mendeleev initially objected to spectroscopy and denied the reality of a new element called helium, saying that its strong yellow line (D_3) was just some known element under unusual circumstances. He came around to roughly our current opinions before his death in 1907. And third, people can have different views in different contexts. Thus, George Biddell Airy (as director of the Royal Observatory and Astronomer Royal) had very narrow views about what astronomers should be doing, which did not include looking for hypothetical planets or passing starlight through spectroscopes, both when he was wearing his director's hat and when giving public talks or writing popular books (Whiting 2011; Nath 2013). Simon Newcomb, on the other hand (as director of the US Naval Observatory) felt that the work there should be confined to positional and time measurements needed for almanacs and such, but was somewhat broader-minded as the first president of what was then the Astronomical and Astrophysical Society of America, and very broad as a writer for the general public (Newcomb 1906, where he suggests some small change in Newtonian gravity to fit observations of Mercury and some Ptolemaic-type error as the cause of his contemporaries thinking the solar system is at the centre of the Galaxy or even the Universe).

Third comes the issue of sources. There are primary ones (the papers people published, the notes and letters they wrote, etc. at any given time). I have consulted very few of these de nuovo for this discussion. Second are secondary sources, serious histories and biographies of small or large pieces of science. Hoskin (1997), North (2008), Scerri (2007), Moore (1918) and especially Nath (2013) are those from which I have stolen most extensively. Many others are cited below. Tertiary sources, I suppose, include textbooks like McLaughlin (1961) and popularizations. Still further removed from the original research are books precising textbooks (Hoffleit 1992 on the astronomy textbooks used at Yale) and popularizations (Whiting 2011 on popular astronomy books from 1833 to 1944), dictionaries (especially the Oxford English Dictionary, Simpson & Weiner 1989), and encyclopaedias.

Indeed the thought that I might be able to say something slightly original on the present topic came from the possession of the 1914 edition of Winston's Cumulative Encyclopedia (Morris 1914). Cumulative meant that there were places provided for gluing in new pages at the ends of each alphabetic letter. The 12 volumes (A-BEN to T-ZYM) were purchased by my paternal grandparents not for my father (b. 1912) but for his elder brother, John Allen ("Jack" b. 1902) and were rather out of date even for their time, declaring, for instance Brownian movement to be completely mysterious. Einstein was not on their radar screen. Nor, of course, was radar, though Marconi had been "broadcasting" for more than a decade.

I do not know what uncle Jack (who died in 1944) thought about scientific issues, but my father, Lyne Starling Trimble, who was trained as a chemist, complained up until his death in

1992 that the whole topic of the composition and structure of atoms and nuclei properly belonged to chemistry, and the physicists had stolen it. The last chapter of Moore (1918) makes clear that he would have agreed.

2. What was, and is, astronomy?

The word is the oldest of the three, according to the OED (Simpson & Weiner 1989), traceable back to 1300 and then equivalent to astrology. Astronomy and astrology separated in the 17th century, Kepler having done both. The Greek roots mean "star arranging" (perhaps one who mapped out constellations) and "star words".

2.1 Astronomy in 1863

This was the year in which William Huggins, an amateur astronomer, began to work with his neighbour, William Allen Miller, a professional chemist of University College London. They found that a few nebulae (previously thought to be unresolved star clusters) showed bright line spectra and were, therefore, hot and gaseous. Complete acceptance took a while, as was the case for the contemporaneous demonstration by Robert Bunsen (a chemist) and Gustav Kirchoff (a physicist) that the spectrum of the solar photosphere had absorption features attributable to iron and sodium, and, later, many other terrestrial elements. National, as well as disciplinary, disputes were common then as now, and J.D. Tait attempted to make the case that British physicist and astronomer Balfour Stewart had really done most of the things for which Bunsen and Kirchoff got credit (see the article on Stewart in Hockey et al. 2007 for a modern view).

On the traditional, positional astronomy side, no radial velocities, a handful of parallaxes (dating from 1838 and thereafter), and several hundred proper motions were in the catalogues, that last enough for F.W.A. Argelander (using northern hemisphere stars) and Thomas Galloway (using southern hemisphere stars) to have determined that the solar system is moving in the general direction of Hercules, relative to nearby stars. This tradition of finding the solar motion relative to some specific population, later including radial velocity data, eventually led to the discovery of the rotation of the Milky Way and of Hubble's Law.

Meanwhile, as it were, the textbooks used at Yale (Hoffleit 1992) discussed telescopes, coordinates, mapping the sky (uranography) and earth, but of the specifically astronomical content, only 10-15% concerns stars and the stellar system. This is probably the place to say, in case I forget later, that elementary astronomy textbooks generally try to cover all of what is going on in the field at the time of writing. The same cannot be said of introductory college physics books, which are strongly focussed on mechanics, electricity and magnetism, elementary quantum mechanics, and a few other basic topics like wave motion, heat, and sound. Chemistry comes somewhere in between. Astronomy at Yale in those days was a junior level course. Two popular books by John Herschel (Whiting 2011) from 1833 and 1869 bracket our reference year and again devote only a little more than 10% of their pages to star clusters, nebulae, stars, and the Milky Way. And much of the solar system material concerns motions (including perturbations) and masses rather than surfaces or interiors or formation.

2.2 Astronomy in 1913

According to the 1914 encyclopaedia (Morris 1914), astronomy had three parts: descriptive (meaning constellations, motions in the sky, face of the moon etc.), practical (meaning positions and proper motions for navigation and surveying), and physical (meaning the causes of the motions). Celestial photography and spectrum analysis counted as recent advances, the latter having yielded radial velocities and something about elemental composition, but also the conclusion that the body of the Sun was solid (or, according to Jeans up to 1929, at least not gaseous, Whiting 2011), The main topics were Sun, moon, planets, fixed stars, comets, nebulae, meteors, and the "hypothetical Vulcan".

The physical constitution of comets was said to be an enigma, though spectra dated back to the 1880s, and, of course, Halley had come and gone in 1910. For many more items known and unknown about comets in each of our epochs, see Yoemans (1991). Quite generally, encyclopaedias and textbooks tend to lag what is going on among full-time scientists, and for astronomy, this is probably clearest in 1913. This was, after all, the year when H.N. Russell first showed his color-magnitude diagram in public (at a meeting of the Royal Astronomical Society). But of the texts used at Yale bracketing the year, C.A. Young (of Harvard) was up to 29% extra-solar-system material and E.A Fath (the discoverer of the first Seyfert galaxy, but long gone from Lick and Mt. Wilson) had 42%.

The local focus was not just a property of things published in the USA. Comas Sola (1928 and a sort of coffee table book) is almost exactly 2/3rd "how to look at the earth and sky" and solar system material.

On the popular book front (Whiting 2011) Simon Newcomb in 1902 puts only about 13% of his pages outside the solar system, hardly touching on stellar motions, binaries, and such, while Eddington (in 1928) and Jeans (in 1929) are almost exclusively stellar, relativistic, and astrophysical (a word that can hunted back to 1880 in the OED, or even further if you don't object to a hyphen). Does this mean that no one was still working on positions, proper motions, radial velocities, solar motion, Galactic structure, and so forth? No, of course not. Indeed each of these still had major advances to come. What it does mean is that astronomy, even at the basic level, had become broad enough that bites less than the whole thing were more than enough to fill a hefty book. That most colleges and universities still try to cram the entire Universe, from comets to cosmology, into single books and semesters has come to distinguish our subject from most others!

One demographic item, 1913−14 seems to have been the moment when E.C. Pickering (in the middle of a long term as president of the AAS) had the maximum number of "computers" on his staff at Harvard. There were 14, many working on classification of spectra, but also measuring positions and brightnesses of stars, asteroids, and all on photographic plates. The first woman to have arrived there and carry out standard astronomy research was Cecila H. Payne (later Gaposchkin) in 1923. There were not a lot of women researchers in any field any place else in those days either!

2.3 Astronomy in 1963

The technical literature for the period 1960−64 (Trimble 2009) consisted of about 1/3 stellar papers and a bit more than 20% each of solar system, Milky Way, and extragalactic. Radio astronomy was creeping into the mainstream (with many new telescopes built about then, and the US about to catch up with the UK, Australia, and Netherlands); and X- and gamma-ray astronomy was still one flight = one paper, but also beginning to appear in the astronomy and astrophysics journals as well as in physics ones.

Radio astronomy had come largely out of radar programs from World War II, meaning that the people were often engineers or trained on the job, and this (along with the initially very poor angular resolution and dominant sources so different from those in the optical sky) undoubtedly contributed toward the reluctance of traditional astronomers to accept that it was going to be very important, again from comets to cosmology. Radio source counts, for instance, ruled out a steady state universe well before the discovery of the microwave background (Longair 2006). Remember how folks defend territories!

This was the year of the official discovery of quasi-stellar radio sources (QSRSs, later quasars) and of the first "Texas" symposium on gravitational collapse and other topics in relativistic astrophysics. It included radio results and glimmerings of general relativity. The 27th "Texas" is scheduled for December, 2013, back in Dallas where the first took place, after wandering as far afield as Germany, England, Australia, and Brazil (number 26 in December, 2012).

The 1961 text by McLaughlin (1961) freezes in time the view of a mainstream optical astronomer, who has incorporated the contributions from nuclear physics over the previous 25 years, but not those of general relativity, and not all the recent observations. A summary of topics and my reaction to them are as follows.

Borderline territory with geology well explored (age of the Earth and Sun; rock types, preplate tectonics attempts to understand Earth's surface). Pages almost equally divided between solar system (plus telescopes etc.) and extra-solar systems, meaning stars, galaxies, and the Universe. Uses both cgs and "customary units" (miles per hour and such).

The Sun runs on the pp chain and more massive stars on the CNO cycle. Stellar evolution in HR diagram in pretty good shape (ideas of Sandage and Schwarzschild). White dwarfs are simple cooling off. The evolutionary status of Cepheids and horizontal branch stars in globular clusters to be determined. Star formation is an on-going process (it had not been 20-30 years before), but the pre-main-sequence tracks are radiative, not the convective ones we credit to Hayashi, and so seriously wrong. Helium burns on to carbon and beyond as per B^2FH.

Some supernova remnants are synchrotron sources (about the only look-in for radio astronomy). No neutron stars or black holes by any name; but Thornton Page, teaching at UCLA in 1963 insisted that it was unreasonable to expect all the OB star elephants to end up as white dwarf mice, and that there must be some sort of heftier remnant possible. No supernova mechanisms are suggested, though Type I and II (without and with H, the latter fainter and more common) are distinguished. Novae are shown on an HR diagram as something that happens to single white dwarfs during the cooling process.

Radio galaxies are declared to be colliding galaxies and S0's the result of collisions in clusters. Among ordinary galaxies, only the six dwarfs in the Local Group are known. Spiral arms are attributed to shearing (like flocculent spirals today but those with two long, dominant arms ("Grand design") are said to be the commonest sort and puzzling.

Masses, 10^{11} $M_{\odot}$ for the Milky Way and $2{\times}10^{11}$ $M_{\odot}$ for M31, that is $M = V^2R/G$ and rotation out to the optical edges. Clusters are common, (including de Vaucouleur's supercluster) though not all galaxies are clustered. Cluster masses (from velocity dispersions) are $5{\times}10^{15}$ $M_{\odot}$ for Virgo and 10^{17} $M_{\odot}$ for Coma, interpreted as either lots of intergalactic something or unbound, and (like about half the participants at a 1961 symposium on the subject, Neyman et al. 1961) he favours unbound. (Incidently the Page among those editors is the same Chap who expected dense massive stellar remnants).

On the cosmic scale, the standard Hubble (1929) paper is indicated as evidence for an expanding Universe, but McLaughlin (1961) puts "redshifts" in quotes and doubts that the expansion is real.

2.4 Astronomy in 2013

Circumspexi (look about you, as somebody is supposed to have said to somebody else who was looking for a monument to Christopher Wren in 18th century London). That is, look at the topics of abstracts at any meeting of a large astronomical society or at the table of contents of any astronomy 101 textbook you have been urged to adopt by its publisher, except that these still tend to over-represent the solar system, because of the marvellous pictures available from space programs. Perhaps some balancing of that effect is one of benefits attributable to the Hubble Space Telescope. But the most recent large sample of research papers I've looked at (about 4500 from 11 journals, including Icarus, but not Solar Physics; Trimble & Ceja 2010) has the following fractions of papers by subject matter, for those papers including at least some observational data or comparison of theory with new or archival observations (Table 1):

Very different obviously from earlier snapshots, but optical observations are still the largest slice, and stars very important, though the most-highly-cited papers are in gee-whiz territories, es-

Table 1. Fractions of papers by subject matter.

Solar system and Sun	0.04	High Energy Astrophysics (AGNs, NS/BH/XRB)	0.22
Exoplanets	0.02	Milky Way, ISM, Star Formation	0.16
Cosmology and GRBs	0.06	External Galaxies and Clusters	0.18
Service, Catalogues, etc.	0.05	Stars, Binaries, Star Clusters	0.20

pecially cosmology and exo-planets, topics which hardly existed in earlier intervals. The numbers are subject to various reservations (Trimble & Ceja 2010) but are probable a fair representation of what astronomers in relatively prosperous countries are doing. A good many papers in the invasion topics of dark matter, dark energy and inflation appear in physics journals.

The topics highlighted in textbooks probably lag somewhat. Also not very informative (unlike for chemistry & physics in 2013) are the divisions of the American Astronomical Society, which for odd reasons address only topics historically out of the mainstream. The Divisions of the International Astronomical Union, whether the brand new 2012 system or the previous one, undoubtedly under-represent (relative to research papers) extragalactic and high-energy topics. This should, perhaps, not be thought of as a criticism, because the Union is charged, under various international agreements, with keeping track of time standards, positions and proper motions, and nomenclature, mostly in the solar system.

3. What was and is, chemistry?

The word appears, as distinct from alchemy, in 1605 (OED) and derives from the Greek chemia, "infusion". The distinction was perhaps not fully complete until about the time of Priestley (1788). Newton, and Boyle, you may recall did a good deal that we would now call alchemy, seeking to transform base metals into gold and so forth. British English long continued to say "chemist" where other dialects said "druggist", "pharmacist" or "apothecary". For a century or more, ending only rather recently, historians of science thought of alchemy as nigh on to untouchable, though as Principe (2011) and others have begun to rediscover, the medieval "chymists" did some very interesting things (some of which can be reproduced) by methods that we would now say were essentially scientific. No gold from silver, sadly, except by adding about 84 neutrons and waiting a long time, but a fairly revolting solution into which you can dip silver coins (if you can find any these days) and have them come out looking like gold.

3.1 Chemistry in 1863

Arguably the most important item for this epoch is that measurements of atomic weights by Berzelius and others had become sufficiently numerous and sufficiently accurate to permit recognition of various sorts of patterns by Oskar Lothar Meyer, Dmitri Ivanovich Mendeleev, and whomever else you might want to credit (Scerri 2007, Moore 1918). I was taught in childhood to regard the periodic table as one of the most beautiful things in the world, and students in non-major courses can still be persuaded to take at least a modest interest in that way of summarizing an enormous amount of information. About 20 years ago, when California (and many other states) were attempting to establish standards for the science to be taught in grades 1-12 (ages 6-18 or so), there was a considerable kerfuffle over whether only pupils on some sort of pre-college track should be allowed to see a periodic table or whether it should be shared with all. Glenn Seaborg (whom you will met again later) was at least nominal chief of the "Table for all faction". I don't actually know who won.

Other items that had recently been put in place included (1) Dalton's atoms, though they were not enormously popular (perhaps owing to confusion from the phrases "molecules elementaires" in chemistry and "molecules integrantes" in physics, our modern atoms); (2) the ideas we associate with the names of Avogadro and Loschmidt (though numerical values came later); (3) the notion of electrolysis as a legitimate part of chemistry (an invasion from physics that had initially been resisted); (4) the laws of definite proportions, multiple proportions, and combining weights, which come out of chemical reactions between gases and neutralization processes, and (5) the concept of chemical affinity as being essentially electrical (which came from Faraday, who undoubtedly had credentials, based on his work, not his education, as both a chemist and a physicist).

There was not yet any very coherent theory of organic chemistry, though something approaching modern notation had been proposed and would be explicated in a major text book by August Kekule (of the benzene snake) a few years later. Item (4) is clearly somehow associated with the then-new notion of valences, to which one of the main contributors was Edward Frankland, whom you will met again (if I don't forget) as the chemist collaborator of astronomer (etc.) Norman Lockyer, the discoverer of helium in the sun.

For what it is worth, Lothar Meyer and Mendeleev soon after each also produced a major chemistry text, and again the better-known one came slightly later, and in both Russian and German (Gordin 2012)

3.2 Chemistry in 1913

This is, I think (inexpertly), the most fascinating of the snapshots, because chemistry looked so very different from different viewpoints at essentially the same time. I'll touch on three. Morris (1914) indicates that the primary topics in the subject are the laws of combination, atomic weights, nomenclature (acids, bases, oxides) symbols (essentially our current ones for the elements, which go back to Berzelius in 1812, a bicentenary to be celebrated!), atomicity, molecules, compound radicals (more nearly our view of charged multi-atomic entities rather than the older one of things that combine with oxygen), classification of compounds, and the organic/inorganic distinction.

Moore (1918) of course knew about these matters, pointing out, for instance, that the classification problem was most acute in organic chemistry. The paragraphs that he devoted to August

Wilhelm Hofmann's 1864 return to Germany from London and to the coal tar industry foreshadow, first, the problems that Britain and France would have with supplies of many chemical substances starting in 1914 and, second, the focus of current chemistry on practical matters (Sect. 3.4)

But Moore's final chapter is called "Radioctivity. Its influence upon the atomic theory". And the Section headings are: X-rays; Experiments by Bequerel; Discovery of Polonium and Radium by Madame Curie (indeed Pierre doesn't even make the index, though frogs' legs do, for Galvani, not dinner); Rutherford's work on Thorium; his theory of atomic disintegration: character of the products (α-rays are known to be He nuclei and β-rays the same as electrons; γ-rays are still uncertain); Helium from Radium; Details of radioactive transformations; Light thrown by radioactivity upon the nature and dimensions of the atom (at last a concrete number for Avogadro, though this could have come from earlier chemical methods, Schroeder 2000); Genetic relationships of the radioactive elements (in a notation no longer used or easy to read); Isotopy; X-ray spectra; Their use for studying the arrangement of atoms in crystals (the Braggs); Moseley's comparison of different spectra; The atomic number and the periodic law. A few other subsections are not mentioned in the table of contents (effects produced by single atoms; structure of the atom; radioactivity and cosmogony). The final sentence is "The properties of the elements are periodic functions of their atomic numbers".

All of these indicate that at least some chemists were poised to claim the atoms and nuclei as part of their territory. By the time of our next snapshot, the physicists had taken over, and have really never let go, a fact which my father was still bewailing decades after.

Meanwhile, as it were, "The recent war (WWI) as never before in the history of the world brought to the nations of the earth a realization of the vital place which the science of chemistry holds in the development of the resources of a nation" (J. Stieglitz in Slosson 1919). Slosson's book is utterly fascinating and deals largely with things chemists knew how to do in 1913 but assisted in expanding to industrial quantities only under the shadow of war. In contrast to Moore's last chapter on theoretical issues, it foreshadows the turn of chemistry toward industrial applications. The chapters address nitrogen fixation (for explosives and fertilizers), coal-tar colours and other derivatives, synthetic perfumes and flavours, cellulose, synthetic plastics, the race for rubber, the rival sugars (meaning beet vs cane, and describing pure sugar as an excellent food), what comes from corn (not just corn oil, animal fodder, and corn syrup!), vegetable oils and oleomargarin(e) etc; poison gases, products of the electrical furnace, and metals old and new. The medicinal side is not yet worth a whole chapter, but the coal-tar discussion includes synthetic antiseptics, pain relievers, and soporifics (the author is not a fan of the last two). Paul Ehrlich ("a German physician of the Hebrew race") is there, but for the antiseptic flavine, not preparation 606! The author is an optimist and ends his first chapter by saying "It is by means of applied science that the earth can be made habitable and a decent human life made possible".

Clearly, physics is neither a borrower nor a lender in Slosson's sort of chemistry. Neither spectroscopy nor X-rays get a look-in, let alone special relativity; and electrolysis (now fully claimed for chemistry) plus traditional beakers and test-tubes (often very large ones!) are the way to get hold of giant quantities of new and useful substances.

Are there still things to be learned from this volume? Absolutely, unless you already a fatty acid fanatic. The chapter "solidified sunshine" gives us the formulae for stearic acid ($C_{18}H_{36}O_2$, fully saturated as in tallow and lard), oleic acid ($C_{18}H_{34}O_2$, mono-unsaturated and etymologically obviously from olive oil), and linolec acid ($C_{18}H_{32}O_2$, from linseed, which makes paints "dry" by taking up oxygen if no H is available). So why fish oil? Because it is largely $C_{18}H_{28}O_2$, elupanodonic acid even more unsaturated than linseed, canola, and all, accounting for the odour and for the now-supposed nutritional benefits. Slosson was in favour of hydrogenating them to a solid (better keeping, more nutritious) form, like Crisco (c). Yes, it existed even then.

3.3 Chemistry in 1963

Glenn Theodore Seaborg (the only Nobelist whose surname is an anagram of Go Bears, the cheering-on of the UC Berkeley football team) is here mostly to get your attention, but from 1940 to 1961 the UCB physics team, headed first by Seaborg and later by Albert Giorso, charged down the actinide line from Plutonium to Lawrencium, yielding only in 1964, when nuclear physicists (yes, they had grabbed the territory of finding new elements) at Dubna produced Rutherfordium. The few gaps in the periodic table left by Moseley's method had, meanwhile, been filled in by Technetium (Z=43) and Promethium (Z=61) after a few false alarms. Tc contributes spectral features to a few highly evolved stars, but was recognized astronomically (by Paul Merrill) about 15 years after the laboratory discovery by Perrier and Segre. Credit to physics or chemistry? Well, the sample was bombarded by deuterons at the Berkeley cyclotron, by arrangement with E.O. Lawrence, so I guess they were physicists. The production and discovery of Promethium (Z=61) in the early 1940s, however, required confirmation by chemical methods (Lide 2005). Seaborg and Lyne Starling Trimble were roughly 2/3rd of the chemistry class at UCLA in 1933. I learned only at the January, 2013 AAS meeting that the father of American astronomer-historian David DeVorkin was very probably the 3rd member of the class.

And in this snapshot, my sins are revealed. It is the year I should have taken a serious chemistry class at UCLA, so that my old textbook collection would reveal what was important in the field. But I opted instead for a year each of Ancient Egyptian Hieroglyphs and of Egyptian Art and Architecture (yielding my first published paper, on the boundary between astronomy and Egyptology).

3.4 Chemistry in 2013

You could perhaps just walk a few blocks to the nearest chemistry department or lab and, ask what they are doing, but in case there isn't one very near, here is a very short and a longer list of what the American Chemical Society (2012) thinks they are doing. The short version consists of the five topics that students must be exposed to for a bachelor's degree to be approved by the ACS: analytical, biochemistry, inorganic, organic, and physical chemistry, including at least 400 hours of laboratory work on four of the five topics beyond elementary courses.

The long version is the list of Divisions (Table 2) that will be participating in the April 2013 annual meeting, technical ones in the left column, administrative, EPO, service, and so forth in the right column, to which there is likely soon ro be added a senior members group. Some of these have been around a long time; the education and history divisions were founded in the early 1920s at the instigation of electrochemist Edward Fahs Smith during his ACS presidency.

Table 2. Divisions of the American Chemical Society

Agriculture & Food Chemistry	Business development & Management
Agrochemicals	Chemical education
Analytic Chemistry	Chemical Health & Safety
Biochemical Technology	Chemical Information
Biological Chemistry	Chemistry & the Law
Carbohydrate Chemistry	History of Chemistry
Catalysis Science & Technology	Professional Relations
Cellulose & Renewable Materials	Small Chemical businesses
Chemical Toxicology	Academic employment Initiative
Colloid & Surface Chemistry	Committee on Economic & Professional affairs
Computer in Chemistry	Committee on Environmental Improvement
Energy & Fuels	Committee on Minority affairs
Environmental Chemistry	Committee on Science
Fluorine Chemistry	International Activities Committee
Geochemistry	Women Chemists Committee
Industrial & Engineering Chemistry	Younger Chemists Committee
Inorganic Chemistry	
Medical Chemistry	
Nuclear Chemistry & Technology	
Organic Chemistry	
Physical Chemistry	
Polymer Chemistry	
Polymeric Materials: Science & Engineering	
Rubber Division	

In addition titles of the scheduled sessions include a great many words that did not exist (or did not exist with the current meaning) in 1963, let alone earlier: for instance, nano-practically-everything, biofuels (though Slosson knew you could make them), antibiotic resistance, drug discovery, oil spills, self-assembly, chirality, CO_2 capture, heterobimetallic, green chemistry, graphene, liquid crystals, and fuel cells. Of these, probably only liquid crystals might be regarded as interlopers from physics, and there are none from astronomy. Of the divisions, only geochemistry might the disputed. There are also, among the session titles, many words that a chemist of 1963 would recognize, including colloids, spectroscopy, batteries, lathanides, actinides, RNA, lipids, combustion, and proteins.

In summary, and considering also the range of articles and new items that have appeared in other weekly issues of Chemical and Engineering News in the past year or so, research is now largely focussed on what would, long ago, have simply been called organic chemistry, with very many medical and industrial applications (though the Society membership continues to include something like 40% academics).

In the "blurring" department, their spectroscopy award is named for E. Bright Wilson (given by the Division of Physical Chemistry) and the nuclear chemistry award named for Seaborg (given by the Division of Nuclear Chemistry and Technology). The Physics in 2013 section below will show rather more grabbing of territory from chemistry.

4. What was, and is, physics?

This is the newest of the words, appearing (OED) in 1589 to mean all of Aristotelian natural philosophy, It comes from Greek for "natural things", and biological topics split off first, then chemistry, leaving something like the present meaning of "matter and energy", though, said W. Watson in 1900 (OED) the line of demarcation between chemistry and physics was "never very clear and of late years practically vanished". We would, I think, no longer say this, though the territories have certainly overlapped.

4.1 Physics in 1863

Was this truly a golden era of stability, with Queen Victoria firmly on the British throne and Newtonian mechanics and gravitation firmly in place, after the triumphal discovery of Neptune, and with LeVerrier's 1859 prediction of Vulcan not yet falsified? Yes, the equivalence of many forms of energy (kinetic, potential, heat, electrical, chemical, gravitational.....) was agreed upon, but just the year before, John Tyndall and Kelvin thought 100% of the credit should be given to Julius Robert Mayer, while Joule and Kelvin would have taken much for themselves (Lindley 2007).

On the electromagnetic side, everything we associate with the name of Michael Faraday (d. 1869) was in place. J.C. Maxwell had put his eponymous equations into recognizable form in 1861-62, and was just announcing to the British Association "the elementary relations between electrical measurements". But it was not until 1881 that our names for the units of charge, current, potential, resistance, and capacitance and the methods by which they were to be measured, were agreed upon, without Maxwell who died in 1879 (Lindley 2007).

Light was a wave since it diffracted and was quite possible a wave in luminiferous (light-carrying!) ether. Kelvin was an etherist to his death as well as scoffer at the displacement current, and had concluded that both earth and Sun were at most 10^{7-8} yr old, the former from its present temperature and the rate of heat flow through rocks, and the latter on the assumption that solar luminosity must derive from contractions and gravitational potential energy. In a chauvinist dispute, Kelvin's friend P. G. Tait said repeatedly that the Germans, Bunsen and Kirchoff were getting some of the recognition that belonged to the British Balfour Stewart.

William Whewall had coined the word "physicist" in 1840, to distinguish those so-called from physicians. "Scientist" was also at least partly his word a bit earlier, though science, from the latin scire, to know, can be traced back to 1340 (OED) in the sense of belief or opinion. The modern sense, "body of knowledge", was used by Watt in 1725.

4.2 Physics in 1913

I am inclined to think that this is, for physics, as for chemistry, the most interesting snapshot, because of very rapid change toward what we now think of as belonging to the subject. Morris (1914) defined physics as natural philosophy, or study of the phenomena of the material world, or of the laws and properties of matter, or more restrictedly the properties of bodies as bodies and phenomena produced by the various forces on matter in the mass (which would perhaps have left atoms and nuclei for chemistry!). Chief branches were dynamics, hydrostatics, heat, light, acoustics, electricity, and magnetism. Other articles addressed gravity (meaning on earth), gravitation (meaning Newtonian force, but only solar system applications mentioned), gas laws, thermodynamics, Brownian movement ("cause unknown" though 8 years post-Einstein), heat, sound, and a few other topics.

But with 20-20 hindsight, we can remind ourselves that 1905 had already seen Einstein explaining the photoelectric effect and Brownian motion as well as special relativity. It was the year of the Bohr atom and initial steps toward quantization (and the take-over of chemistry). The 1911 Solvay conference (Straumann 2012) brought together 18 famous scientists, mostly physicists (though Ernest Solvay, who paid for it, had been trained as a chemist and had some very strange views about Brownian motion, gravitation, radioactivity and so forth). Bohr was not one of the 18 (Denmark being represented by Knudsen), and indeed it was well into the 1920s before conceptual objections to Bohr's atomic theory, from chemists as well as physicists died away (Kragh 2012)

The centenary of the discovery of cosmic rays was widely celebrated in 2012, and, although early work of tracing out their properties definitely belongs to physicists (Walter & Wolfendale, 2012) the task of accounting for their origins was dumped onto astronomy. Walter Baade and Fritz Zwicky (1934) were among the "early responders", proposing supernovae, while Hungarian physicists Barnothy and Forro (1935) said firmly "not novae" in opposition to an earlier claim by Kohlhörster.

Millikan was initially on the wrong side on several cosmic ray issues. Serious physics was fairly new in the US, and Millikan (1913) "On the elementary electric charge and the Avogadro number" was one of the first significant, modern papers to appear in Physical Review (Stroke 1995). The next year he reported a direct measurement of the numerical value of h, and T. Lyman pushed the observed laboratory spectrum of hydrogen to 905 Å, thus taking in the series of lines that now bears his name. W.D. Coolidge at General Electric announced the construction of a powerful Roentgen ray tube, also in 1913. He used German glass, so physics, like chemistry would not escape unscathed from the onset of WWI. Irving Langmuir, one of the physics-chemistry borderland folks, also published in Physical Review in 1913, but I don't fully understand the significance of his paper, though it was one of the ones selected for reproduction by Stroke (1995).

4.3 Physics in 1963

This was the year that the founders of the University of California, Irvine physics department began to gather. The decision was made to include particle physics, solid state, plasma, and astrophysics (somewhat later), but not nuclear physics or atomic, molecular, and optical physics. The department is now all over the place, for reasons mentioned at the end of the next section.

The divisions of the American Physical Society founded up to 1963 were: Atomic, Molecular and Optical (established as Electron & Ion Optics, 1943), Polymer (1944), Condensed Matter (established as Solid State, 1947), Fluid Dynamics (1947), Chemical Physics (1950), and Plasma Physics (1959). I think chemical physics is different from physical chemistry (an ACS division), but polymers sound the same for both.

As was the case in 1913, though perhaps not quite so extremely, there was a considerable gulf between what was perceived as " new" at the textbook level and at the research level. The first edition of physics for students of science and engineering (Resnick & Halliday 1960; Halliday & Resnick 1960) had just been published, nearly all in MKS units. The authors wrote that the contemporary topics for which they had made room included atomic standards, collision cross sections, intermolecular force, mass-energy conversation, isotopic separation, the Hall effect, the free-electron model of conductivity, nuclear stability, nuclear resonance, and neutron diffraction. The topics left out in their favour were about 20, including viscosity, surface tension, acoustics, AC circuits, electronics, colour, photometry, change of state, and a good many others that one might now say are on-going puzzles.

By 1963, the US was the leader, and Physical Review the leading journal, in many branches of physics, and the papers from that year and the previous one selected by Stroke (1995) include a good many "Wow!" and "Gee-whiz" items. A subset: (1) several laser items by Maiman et al., (2) Kleppner, Goldenberg & Ramsey on theory of the hydrogen maser, (3) Gell-Mann on symmetries of baryons and mesons, (4) a 7-author, alphabetical team, with Lederman in the middle on existence of two types of neutrinos, (5) Anderson & Rowell on probable observation of Josephson superconducting tunnelling, (6) Linsley's 10^{20} ev cosmic ray at Volcano Ranch (which had to get to us through the 3 K cosmic microwave background, not yet quite discovered, but when it was, a good many physicists started moving in on that astronomical territory), (7) Brans-Dicke theory of gravity (actually 1961, my one cheat here), (8) Roy Kerr on the gravitational field of a spinning mass (the Kerr metric), (9) a couple of NMR papers and a couple on the Percus-Yevick equation (um, er), and (10) Glauber on quantum theory of optical coherence. Numbers

(7) and (8) clearly have implications for astronomy and cosmology, and a couple of others for chemistry, but I think only (6) and its successors trespass seriously.

4.4 Physics in 2013

The American Physical Society has fewer divisions, working groups, forums, and such than the American Chemical Society (its membership is small smaller by a factor of around three). Those that have come into being since 1963 are (Table 3):

Table 3. New Divisions of the American Physical Society since 1963

Nuclear Physics (1966)	Physics & Society (1972)
Particles & Fields (1967)	History (originally a Division, (1980)
Astrophysics (as Cosmic Physics 1970)	International (1985 as Topical Group)
Biological Physics (1973)	Education (1992)
Material Physics (1984)	Industrial & Applied (1995)
Laser Science (1985)	Graduate student Affairs (2001)
Physics of Beams (1985)	
Computational Physics (1986)	
Instrument & Measurement Science (1984)	
Shock Compression of Condensed Matter (1984)	
Fewbody Systems & Multiparticle Dynamics (1985)	
Precision Measurement & Fundamental Constants (1987)	
Gravitation (1995)	
Magnetiscm & Its Applications (1996)	
Statistical & Nonlinear Physics (1996)	
Plasma Astrophysics (1998)	
Hadronic Physics (2001)	

Notice that the division of astrophysics (captured territory?) was originally called cosmic physics, and many of its founders and early officers came from the cosmic ray community. The present membership includes a number of high-energy astrophysicists, and the overlap with the American Astronomical Society membership is about 50%. One prize, named for Hans Bethe, is given jointly by the nuclear physics and astrophysics divisions, and its winners have come from the theoretical, nuclear laboratory, and most recently, observational astronomy communities.

A few of the Divisions (etc.) seem to be shoving into chemical territory (biological physics, materials physics), and at least seven of the major APS prizes live on the boundary. These follow, with the topic, if not obvious from the name of the prize, along with names of a few of the winners, who give, I think the flavour of those boundaries (the selection is a highly prejudiced one).

Biological Physics (Ed Purcell, Hans Frauenfelder)
Broida (atomic & molecular spectroscopy, chemical physics; Steven Chu, Ahmed Zewali)
Davison-Germer (atomic or surface physics; Norman Ramsey, Walter Kohn, Dalgarno, Kleppner, Larry Spruch, Happer)

Isakson (optical effects in solids; Elias Burstein, Paul Fleury)
Irving Langmuir (Chemical physics; Van Vleck, Slater, Rentzepis, Herschbach)
Plyler (molecular spectroscopy; Townes, Klemperer, Herzberg, Saykally, Zewali)
Adler (materials; Ellen Williams).

Reactions to this sort of invasion? Either, "well, our people (chemists, astronomers) are so good that even the APS gives them prizes", or, from the other side, "why are we giving this guy a prize? He's a chemist!"

5. Forgive us our trespasses

Most of the sections above include examples of friction at disciplinary boundaries. Here are some more, some of which may lead you to feel that this article should have been called "Bombarding the Boundaries" rather than "Blurring" though in most cases I think the processes were fruitful.

5.1 Forgive us our trespasses - astronomy

Invaders of astronomical territory have included photography, spectral analysis, nuclear physics, special and general relativity, and, most recently, high energy and particle physics. Even photography was not wholly unopposed, although astronomers (John Herschel, Henry Draper, whose father John William was the founding president of the American Chemical society, and many others) were among the pioneer users of, first wet collodion emulsions (replacing the slower daguerreotypes) and then dry emulsion plates. Among those who preferred drawings to early photographs were Lowell for Mars, Langley for sunspots, and Binden Stoney for the Orion Nebula (North 2008, pp. 481, 505, and 519). Now there is no doubt that the drawings show finer and more interesting details than the early photographs. BUT, as only gradually became clear as photography improved, many of them weren't actually there. (The Mars case is best known.) The photographers were virtually always right, and, more recently they defended their emulsions as more productive of astronomical data than the early phototubes, CCDs, and so forth. You are perhaps too young to remember just how scruffy those were and how small the fields of view. Again the later technologies have almost completely triumphed, and my skills in cutting tiny spectrographic plates and sloshing developer have not been needed for some time.

Airy's and Newcomb's objections to the use of national observatory time to look at chemical compositions rather than carrying on with position, proper motion, and time measurements of use to navies and merchants have already been noted. Airy's statement that the appearance and character of the surfaces of celestial objects is of "no proper astronomical interest" surely takes the head-in-sand-award of the century. But it is the names of those who welcomed spectroscopy that are most likely to be remembered – Bunsen & Kirchoff, Huggins, Lockyer who found helium in the Sun, Angstrom who, earlier, had demonstrated the presence of hydrogen there, Rowland with his magnificent 1880 photographic atlas of the solar spectrum that led to the identification of some thing like 55 elements there by the end of the 19th century, and so forth (North 2008, Ch.

15; Nath 2013). Of course there were other spectroscopic astronomers who identified coronium, nebulium, orionium casseopeium, aldebarium and a few other non-elements not responsible for specific emission and absorption lines in stars, nebulae, and the Sun. Moseley's 1913 idea helped a good deal in eliminating those from the astronomical inventory, in contrast to J. W. Draper's 1876 suggestion that each star might have some individual elements of its own.

The British chemist William Crookes (see Trimble 2010) supposed that a few primordial substances (perhaps hydrogen, helium, coronium, and ether, some with A<1) might be found in the nebulae and gradually transformed to terrestrial elements as material cooled and formed stars and planets. It is probable that he also didn't understand his radiometer very well. The purpose of A<1 elements was to allow Prout-like assembly of more massive elements, whose weights were clearly not integers, from the light ones. Again that sort of chemical evolution did not survive the advent of atomic number.

An important lesson should have been that cosmic abundance vs. Z and vs. A were going to be different things. It was learnt slowly (some details in Trimble 2010). For instance, Aston, whose atomic mass measurements are part of the story "How we know stars run on nuclear energy", as late as 1924 was using A for his horizontal coordinate, but plotting elemental abundances. He was disappointed at how ragged the plot looked, still with no obvious patterns, at least vs chemical properties. In fact his numbers show lots of those elements (C, O, Mg, Si, S) that you might think of as being assembled from alpha particles, as well as the odd-even effect, that is abundances depend on nuclear properties not chemical ones. It is essential to plot individual nuclide abundances, not summed by element, to see the patterns that Burbidge et al. (1957) were finally able to explain by successive neutron captures. And, if you think of a neutron as very like a hydrogen atom, we can now say that William Prout (1815, 1816) was quite right: Everything else is made out of integral numbers of hydrogen atoms.

Many other astronomers made didactic statements on whether their fields should or should not welcome input and collaborations from various parts of chemistry and physics. A very few examples (many culled from Nath 2013): Laplace and Somerville (1834) thought that all sciences were and should be connected. Of the chemists, Frank Wigglesworth Clark in 1873 and J.W. Draper in his 1876 presidential address to the first meeting of the American Chemical Society thought that stars might and should have elements not found on earth, perhaps some with atomic weights less than one.

Much closer to the present, Richard C. Tolman, whom most of us associate with relativity, thermodynamics, and cosmology, began life as a chemist and approached the problem of trying to understand the composition of the universe from the point of view of chemical equilibrium (Tolman 1934).

Jumping to the present, astrochemistry is now a recognized word (OED spelled it astrochymist from 1876) and discipline (Thielens 2012; 20 September 2012 press release from ALMA; or if you want whole books, Miller 2012, and Cernichero & Bachiller 2012). The focus now is on molecules in the interstellar medium and star formation regions, of which some 170 are now known, some unheard of on earth, like HC_9N. People with the expertise to figure out which bands and other features can be associated with which molecules are highly valued. William Klemperer of the Harvard chemistry department was one of the first to answer the call, on the theory side. And Luky Ziurys of University of Arizona is one of the outstanding laboratory chemists on our side (meaning both of the subdisciplinary divides and of the Atlantic).

The most recent invasion and territory-grabbing from physics have been in the topics called dark matter, dark energy, inflation, and multiverses. What would Moseley have thought? Born in 1889, he could, in a parallel, warless universe have reasonably lived to hear about the early evidence for dark matter, summarised in a couple of 1974 papers. My own views, probably not all endorsed by any one colleague are (1) dark matter–existence firmly established; nature to be determined, (2) dark energy – very probably, and no objection to its turning out to be indistinguishable from a plain, old, chocolate cosmological constant, (3) inflation – a bit like the aluminium siding folks used to try to sell you over the phone, a solution to problems you didn't know you had (causality, monopoles and all) until they told you about them, (4) multiverses of some sort–very much in line with the gradual non-uniqueness of, first, our vantage point, then our star, our Galaxy, our cluster and supercluster, and planet.

5.2 Forgive us our trespasses - chemistry

I don't know of any examples of chemistry or chemists feeling threatened by astronomy or astronomers, unless you count helium and the coronim-nebulium gases. Ah, but physics and physicists are different. Neither Volta's and Davy's work on electricity and electrolysis nor the advent of spectroscopy were entirely welcome (Moore 1918; Nath 2013) particularly when Arthur Schuster claimed that spectra would reveal something about the structure of atoms.

And it must be admitted that laboratory spectroscopists also found a good many non-elements (jargonium, nigrium, norium . . .) just as astronomers did. Again Moseley's X-ray spectra made clear that there were not many empty boxes among the rare earths to fit these into. Among those he offended (Scerri 2007) were Masataka Ogawa, who brought him a sample of "nipponium", supposed to be element 43 (it wasn't), and French chemist Georges Urbain who had taken months to figure out that a particular sample contained Er, Tm, Yr, and Lu, by traditional chemical methods (the rare earths being particularly difficult to separate this way because of their electronic structures). It took Moseley about an hour to prepare one of his plates, bombard it with electrons, look at the resulting X-ray lines, and identify the nuclear charges responsible for the X-ray energies present (Scerri 2007). He figured out the relative proportions of the four present the same day, an even more difficult task by Urbain's methods.

The OED quote claiming that the boundary between physics and chemistry was nearly invisible in 1900 was clearly false a couple of decades later. The Curies contributed by noticing that the chemical environment of Uranium atoms did not affect the physics of their decays (rates or products). Gyorgy Hevesy broadened the breach (Dean 2010) by finding Hafnium (Z=72) where Bohr had said it should be based on electron orbits (hiding with zirconium) rather than hiding with lutetium as chemistry suggested.

5.3 Forgive us our trespasses - physics - and conclusion

I am not aware of any territories not already mentioned where physics felt it was being invaded by chemistry. The standard astronomical example is the claim by a small group that non-cosmological redshifts and some form of steady-state universe exist and their anger that physics generally doesn't take them seriously (Burbidge 1997 and references therein for a flavour of the issue).

But sometimes we astronomers win! Classic example, the solar neutrino problem (Bahcall 1989). When Raymond Davis began seeing at most a third of the neutrino flux that astronomers had predicted should come to us from the Sun, physicists and astronomers blamed chemistry (he wasn't getting all the argon atoms out of the perchlorethylene), chemists and physicists blamed the astronomers (well, of course you can't calculate the central temperature of the Sun accurately enough to predict what the flux should be) and astronomers and chemists blamed the physicists (your nuclear cross-sections are wrong, or neutrinos are more complicated than you have supposed). Well, it turned out to be the weak interaction physics at fault. There are 3 flavours of neutrinos in the real world and particles created as one can rotate to the others (MSW effect). Bruno Potecorvo had suggested something of the sort even before the measurements started, and Ray Davis eventually won a Nobel Prize, which some thought Bahcall should have shared. It was a Nobel in physics, though Davis began life as a chemist. A good deal of the early fuss and bother is summarized by Trimble & Reines (1973, which is, of course, in best Matthew-effect way, generally cited as Reines & Trimble).

There is undoubtedly friction on other boundaries, with biologists opposed to reduction of biology to chemistry and chemistry to physics, and philosophers feeling that physics and other sciences are attempting to answer questions that belong to their magisteria. The medieval Latin word magnisterium means the philosopher's stone of alchemy, bringing us almost back to where we started.

My last two thoughts are also (of course) borrowed. First is a sort of paraphrase from Richard Feynman, along the lines that a physicist could learn to do anything that anybody else could do. He had in mind mostly intellectual tasks, but extended to include drumming and drawing. The second comes from an appeals committee convened to deal with a colleague on another campus who objected to not receiving tenure, because the department said what he did wasn't physics. Our decision was that "physics is what physicists do", and so they should award him tenure. They did, and the sort of thing he was working on is now widely distributed over UC campuses.

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