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SOME SELECTED TOPICS IN ACTINIDE, TRANSACTINIDE,
AND SUPERHEAVY ELEMENTS RESEARCH AT OAK RIDGE^{*}

O. Lewin Keller, Jr.

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Moscow Talk

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About three weeks ago Ivo Zvara of the JINR in Dubna joined us in
of
Oak Ridge for collaborative research on the chemistry/the transactinide
elements. Dr. Zvara will be working most closely with Drs. R. J. Silva
and J. R. Stokely. The isotopes of the transactinide elements will be
produced using the heavy ion beams from the Oak Ridge Isochronous Cyclotron
(the ORIC). Up to now, Dr. Zvara and his co-workers at Dubna have carried
out their chemical experiments using very corrosive ^{chloride} reagents. The only
detectors that will stand up under these conditions are for spontaneous
fission; so the chemical work has been limited to the use of isotopes that
have a strong spontaneous fission branching. At Oak Ridge, Zvara and his
co-workers hope to develop chemistry based on less corrosive ^{bromide} reactants that
will allow them to use alpha detectors. This will expand the possibilities
in the study of the chemistry of the heavy actinide and light transactinide
elements since many of their longer lived isotopes decay primarily by alpha
emission. Initially the development work will be directed toward element 105
by doing analogue experiments with niobium.

At the request of Dr. Seaborg, Dr. R. J. Silva is also heading a group
of chemists who will study the chemistry of superheavy elements if the
opportunity arises at the Super HILAC at Berkeley. One of the approaches
being developed for this search is based on the solvent extraction chroma-
tography schemes of Phil Horowitz at Argonne and Russ Baybarz in Oak Ridge.
In addition to U. S. scientists, the team also includes workers from Germany
and Sweden. Silva and Glenn Seaborg have suggested to me that it would be
helpful to predict the chemical properties of more of the elements from about
108 to 120 as an aid in setting up the difficult one-atom-at-a-time chemical
experiments. The tools we have at our disposal for making chemical predictions
are the Periodic System of the Elements, the relativistic Hartree-Fock-
Slater program for calculating energies and radii of electrons in atoms, and

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various approximate theories which have proven useful for a number of years in understanding and correlating certain of the properties of molecules. Several years ago, John Burnett, Tom Carlson, Bill Nestor and I predicted in detail many chemical and physical properties of elements 113 and 114. In the next slide ⁽¹⁾ we see the results of these predictions. For example, we predicted that 113 will have an oxidation potential of -0.6 volts versus a potential for Tl of +0.3 volts. This means, of course, that we expect 113 to be much more noble than Tl, being, in fact, closer to silver in this respect. With its higher electron affinity and polarizability, element 113⁺ will complex more easily than Tl⁺ so that the chemistry of the superheavy element will bear a strong resemblance to Ag⁺ chemistry. For example, the solubility of TlCl in water is not increased by adding excess HCl or NH₃ whereas AgCl dissolves. We think 113 will be more like Ag in this respect. As you can see, we predicted a great many properties for 113 and 114 including the boiling points, melting points, and various radii.

An element that presents us with considerably more difficulties is element 111, eka-gold. As we see in (slide 2), 111 is in group IB with Cu, Ag, and Au. Whereas in groups III-A and IV-A there are easily discernible trends in stabilities of the oxidation states as we go to higher Z, this is not true in group IB since copper is most stable in the oxidation state of II, silver in I, and gold in III. Furthermore (slide 3) the ground state electronic configurations of Cu, Ag, and Au are d¹⁰s¹ whereas that for 111 is computed to be 6d⁹7s². Our approach to 111 chemistry has been to try to identify those electronic factors which appear to be important in determining the chemistry of Cu, Ag, and Au, and to try to evaluate how these factors will balance out in eka-gold. First of all, let's look at the eigenvalues calculated by the rel HFS for the outer electrons of Cu, Ag, Au, and 111. Copper, which is most stable in the divalent state (but has much important chemistry in the

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oxidation state of I) has a separation of 2.7 volts between the $d_{5/2}$ and $s_{1/2}$ levels. In silver this separation has increased to 4.9 volts. It is very difficult to make Ag in the oxidation state of II, and virtually all of the chemistry of this element relates to the I state. In the case of gold, the usual most stable state is III, although much important gold chemistry relates to Au(I). The d-s separation energy is small here ~~as we~~ ^{since} ~~and the $s_{1/2}$ is bound more tightly.~~ ^{and the $s_{1/2}$ is bound more tightly.} ~~the~~ $d_{3/2}$ and $d_{5/2}$ levels splitting has increased. In III the d-s separation is small, and the $d_{3/2}$ to $d_{5/2}$ splitting has increased still further. Due to relativistic effects the $7s_{1/2}$ shell has been stabilized substantially relative to the $d_{5/2}$, and is now actually lower in energy. These effects are at least qualitatively what we expect *on the basis of the trend from Cu to Au.*

The first property to predict about an undiscovered element is its most stable valence state. In order to make such a prediction for III, we must look in detail at why Cu, Ag, and Au have the valences they have. The usual most stable state for gold is the oxidation state of III, ^{as we mentioned,} although gold has much important chemistry in the I state. In gold (III) compounds the ligands always form a square planar arrangement around the gold atom, and the bonding is ^{highly} covalent. This indicates dsp^2 hybridization for the gold orbitals. The valence state, or pre-hybridization state, requires the promotion of a 5d to a 6p electronic shell. That is to say, the electronic configuration of gold that is reactive has the $5d^9 6s 6p$ configuration (slide 4) gold (III) uses the unpaired d, s, and p electrons and also accepts an electron pair from a fourth reacting ligand to form a square planar dsp^2 complex. The bond energy must be sufficient to allow the promotion energy of ~7 eV and also, in addition, furnish sufficient Gibbs free energy to stabilize the complex. ^{Further on next slide #5} Obviously this is the case with gold. But will it be the case with III?

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For 111 the ground electronic state is $6d^9 7s^2$ according to the rel HFS calculation; so the promotion to the valence state is from the $7s$ to the $7p$. According to our calculations this amounts to about 7 eV, about the same as for gold. *the promotion energy to the same valence state* So, if the bond energies of 111 compounds are equal to or greater than those of analogous gold compounds, 111 will react to form dsp^2 square planar complexes. *(Note that heat of sublimation will probably be no problem)* We would expect that 111 would indeed form strong covalent bonds because it is smaller than gold which allows better overlap of its wave functions with those of the ligands. The inner electron repulsion will be larger, but there are indications that this is not of tremendous importance since gold is more covalent than either copper or silver. So we are led to the conclusion that element 111 will be similar to gold(III) in its chemistry, and will probably be at least as reactive as gold.

The next possible oxidation state is II. Gold apparently cannot exhibit a divalent state, and silver only with great difficulty. Copper is most stable in the oxidation state of II. Although just why copper is most stable in the II state is not clearly understood, it probably is the result of a delicate balance between covalent and ionic bonding with the latter winning out because of crystal field stabilization energy. *6* This delicate balance cannot be expected to occur in 111 because of the very high ionization potential of 32.0 versus 28.0 for copper. Even gold at 29.7 eV cannot achieve a II state.

The oxidation state of I for 111 also seems unlikely because of the large ionization potential and small change in radius on ionizing one electron as shown in the next slide. In this slide we take a look at some properties we have extrapolated for element 111 using the rel HFS results as a basis. The first thing we notice is that the first ionization potential of 111 is about 1.7 volts higher than that of gold. This implies that, like gold, 111 will not be ionic in any compound where it has a positive oxidation state, either

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+1 or +3. Furthermore, Cu(I) and Ag(I) are stabilized by the great change in radius that occurs when a single electron is ionized. We see a drop in each case of about one $\text{\AA}$. The smaller radius in each case means much larger lattice energies in crystals or solvation energies in solution. In the case of gold the decrease in radius is somewhat less and in lll we get essentially no change. Gold, which has a change of $0.7\text{\AA}$ forms a quasi-stable oxidation state of I with highly covalent properties. In the case of lll, this tendency will be so much less that we expect lll will not form the oxidation state of I.

This leaves the question of whether lll will have a large enough electron affinity to form the lll^- ion analogous to the auride ion. Obtaining reliable values for electron affinities is a difficult problem both experimentally and theoretically even in the known elements, much less in the superheavies. Our calculations of the electron affinity of lll indicate that it lies between Ag, which does not form a negative ion, and gold, which does. Perhaps the best we can do is suggest that the experimentalists be aware of this possibility.

Our conclusion, then, is that lll will be most stable in the oxidation state of III, and that its chemistry will be similar to gold(III).

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Studies of paramagnetic ions in the 4f and 5f series, the lanthanide and actinides, have been particularly helpful in advancing our understanding of spin-orbit interaction of the electrons in the ions themselves and of their electrostatic interactions through crystal field effects with the other ions in host crystals. In addition, through studies of the hyperfine splittings arising from the interaction of the nuclear magnetic moment with the electronic magnetic moment, the nuclear spin can be determined directly. Such a direct determination cannot be made by nuclear methods, although the spins can be inferred from nuclear data through the use of the shell model.

In order to study such effects actinides and lanthanides are doped into various crystals selected for their symmetry and crystal field strengths. A particularly useful series is furnished by the fluorite type crystals CeO_2 , ThO_2 , CaF_2 , SrF_2 , BaF_2 , and SrCl_2 . These crystals are listed in order of the field strengths they exert on ions doped into them, with CeO_2 being the strongest, and SrCl_2 being the weakest. In CaF_2 , the Ca^{2+} ion is surrounded by eight F^- ions in a cubic array. When the actinide or lanthanide ion is doped into one of these crystals, it therefore finds itself in an electrostatic field of cubic symmetry whose strength depends on the crystal host chosen.

Marv Abraham at Oak Ridge and Norm Edelstein at Berkeley and their co-workers have recently been studying Am^{2+} , Cm^{3+} , and Bk^{4+} in order to advance our understanding of the 5f⁷ configuration and compare it to the 4f⁷ represented by Gd^{3+} , Gd^{3+} , and Tb^{3+} . Although both 4f⁷ and 5f⁷ configurations have ~~the same~~ Hund's Rule ground states of $^8S_{7/2}$, the actinide ions behave ~~as though~~ ^{differently because} they have a considerably larger admixture of non-S-state levels.

First of all ground state splittings for 5f⁷ ions are considerably larger than 4f⁷, being for example, at least two orders of magnitude larger for Cm^{3+} and Am^{2+} in CaF_2 and SrCl_2 than for Gd^{3+} and Eu^{2+} in the same hosts. Also the

the Landé g-factor, g_J , deviates much more from the free-electron value in the actinide ions than in their lanthanide analogues. Edelstein and Easley suggested that the strong spin-orbit interaction in the actinides requires the use of intermediate coupled wave functions. John Conway and Cathy Reinig have generated such wave functions and the results of Abraham and Edelstein and their co-workers support the idea that the intermediate coupling mechanism accounts for the variations in crystal field splitting between the actinides and lanthanides.

Studies of f^7 configuration ions has been considered important because for these ions the orbital angular momentum in the Hund's Rule ground state is zero and the total angular momentum J is equal to the spin angular momentum S . In a fluorite host the cubic crystalline field splits the ground state $(2J + 1) = 8$ degenerate levels of the $^8S_{7/2}$ ground state into two doublets, called Γ_6 and Γ_7 , and one quartet called Γ_8 . The Γ_6 doublet, which is further split by the Zeeman effect, turns out experimentally to have the lowest energy in all of the crystals observed to date. In the next slide (#7) we see the situation presented schematically. What is measured by the electron paramagnetic resonance experiment is the spacing between the energy levels arising from the Zeeman effect. The spectrometer in Oak Ridge, used by Abraham has a fixed RF frequency corresponding to about 0.3 cm^{-1} and the one in Berkeley, used by Edelstein, corresponds to about 1.2 cm^{-1} . Since their apparatuses give complementary information, Abraham and Edelstein have done a number of cooperative experiments over the years. First of all, let's look at what happens to the levels in Cm^{3+} as we change the host from CaF_2 to SrCl_2 . In CaF_2 , the Γ_6 to Γ_8 separation is about 13 cm^{-1} and the Γ_8 to Γ_7 separation is too large to allow a measurement. The crystal field separation is determined experimentally through the perturbation of the Zeeman splitting of the Γ_6 level by the Γ_8 levels. By going to SrCl_2 as a host, however,

the characteristics of the Γ_7 level could be determined because of the weaker crystalline field, and the characteristics of the Γ_8 level could also be better determined through its perturbing influence on both the Γ_6 and Γ_7 , although the actual Γ_8 transitions were unfortunately covered up by radiation damage lines due to chlorine. In SrCl_2 the Γ_6 to Γ_8 separation is about 5 cm^{-1} , less than half the value for CaF_2 , and the Γ_8 to Γ_7 separation has been measured as about 15 cm^{-1} .

Another important case treated by Abraham and co-workers is the f^5 configuration represented by Pu^{3+} and Am^{4+} in the actinide series to be compared to Sm^{3+} in the lanthanide series. The Hund's Rule ground state of $6H_{5/2}$ is split by the cubic field into a Γ_7 doublet and a Γ_8 quartet. In Pu^{3+} , however, the admixture in the ground state of states other than $6H_{5/2}$ is considered to be large whereas in Sm^{3+} this admixture is considered to be small. A quantitative description of this difference in admixtures has been developed in the form of intermediate coupled wave functions by Edelstein. Using these wave functions they calculated crystal field parameters which were consistent with the experimental finding that whereas the Γ_7 doublet is the lowest lying state in Pu^{3+} and Am^{4+} , the levels flip in Sm^{3+} to make the Γ_8 quartet lie lowest. This has been verified for Pu^{3+} in all six fluorite type crystals by both the Oak Ridge and Berkeley groups. Thus the ordering of the ground state levels appears to be considerably different between the actinide and lanthanide cases for f^5 configuration, although they appear to be rather similar for the f^7 .

There is a further area where electron paramagnetic resonance makes an important contribution, and this is in the measurement of nuclear spins. For nuclei, such as $^{245}_{96}\text{Cm}$ and $^{249}_{97}\text{Bk}$ which have an odd number of nucleons, there is a resultant nuclear angular momentum resulting from the spin of $1/2$ plus an "orbital" momentum due to the circulation of the nucleon within

the nucleus. The spin I results in $(2m + 1)$ energy states in a magnetic field as the spin orients itself differently in a quantized manner. In an ion, such as $^{245}_{\text{Cm}}3^+$, which has an electronic magnetic moment, a magnetic field is set up at the nucleus by the circulating and spinning electrons which is parallel to the resultant electronic angular momentum,

J. The $(2m + 1)$ energy levels which result from the nuclear spin I are seen for $^{245}_{\text{Cm}}$ ^{and $^{249}_{\text{Bk}}$} in the slides 8 & 9 from the work of Abraham and co-workers.

The eight lines correspond to a spin of $7/2$, and represent the first direct determination of the spin of $^{245}_{\text{Cm}}$. (Explain why I of $^{249}_{\text{Bk}}$ tricky)

In a series of papers beginning in 1967, Krot, Gelman, Spitsyn and co-workers described their discovery experiments of the valence state of VII for neptunium and plutonium. For Np this VII state was expected, since it possesses the ultra-stable inert gas configuration of radon, but no one had ever been able to attain it before the way was found here in the Institute of Physical Chemistry. In addition to stabilization by the radon-like electronic configuration, Spitsyn et al. recognized that the Np(VII) must also be stabilized by being incorporated into a complex ion, and that the nature of the preparation essentially dictated that it be an oxygenated species. Because of the great stability of UO_2^{2+} , NpO_2^+ and NpO_2^{2+} ions, Spitsyn and co-workers proposed that the complex ion stabilizing the high valence state might be formulated schematically as shown in the next slide ^{#10}. The NpO_5^{3-} ion is conceived to incorporate the well known linear O-Np-O grouping, and it was thought that the stabilizing effect could derive from this source. In order to obtain more direct structural information on this new species, John Burns, Willis Baldwin, and Jim Stokely undertook in our Laboratory to grow a suitable single crystal containing Np(VII) and to obtain its structure using x-ray diffraction techniques. The first step in the preparation of a suitable crystal involved oxidizing Np(V) to the (VII) state following a procedure similar to that devised by Spitsyn and co-workers

as modified by Zielen and Cohen. Efforts to obtain suitable single crystals of the compound crystallized by Spitsyn and co-workers by adding hexaminocobalt chloride to the oxidized Np in solution were unfortunately unsuccessful because the crystals were too small. Fortunately, in a conversation with Larry Asprey of Los Alamos, he suggested trying a diffusion technique, and this method did lead to the production of excellent single crystals through slow growth. In this diffusion approach, a 0.015 N solution of Np(VII) in the bottom of a test tube was carefully covered with a layer of 1 N LiOH and then a top layer of 0.02 N $\text{Co}(\text{NH}_3)_6\text{Cl}_3$ was added. As the hexaminocobalt complex and Np(VII) diffused together in the LiOH layer, perfect pyramidal, green crystals formed on the walls of the tube. These crystals were subsequently found to be a new compound, (next slide, please), Slide #11, $\text{LiCo}(\text{NH}_3)_6\text{Np}_2\text{O}_8(\text{OH})_2 \cdot 2\text{H}_2\text{O}$ rather than the compound prepared by Spitsyn et al., which they formulated as $\text{Co}(\text{NH}_3)_6\text{NpO}_5 \cdot n\text{H}_2\text{O}$ ($n = 2$ to 3). I will steal my own thunder by mentioning that Burns and co-workers suggest that this second compound should probably be written $\text{Co}(\text{NH}_3)_6\text{NpO}_4(\text{OH})_2 \cdot n\text{H}_2\text{O}$ with $n = 1$ to 2 . The crystal structure analysis began with precession photographs which established the crystal system as monoclinic. Subsequent measurements of 1728 reflections were made for the crystal structure determination using a computer controlled 4-circle diffractometer. The intensity of a reference reflection was made hourly, and its intensity was found to change less than 5% during the run. Absorption corrections were made using the program of Wehe, Busing and Levy. The validity of crystal structure determinations is generally judged through a so-called agreement index, R. For the structure of $\text{LiCo}(\text{NH}_3)_6\text{Np}_2\text{O}_8(\text{OH})_2 \cdot 2\text{H}_2\text{O}$, Burns and co-workers obtained an agreement factor of 0.057. For simple compounds, agreement factors as small as 0.02 are obtained, and for complicated compounds agreement factors in the range of 0.08 to 0.1 are not uncommon. So we can say that the structure of this crystal has been correctly determined

since the determination meets and even exceeds the criteria set by crystallographers to judge their work. In the next slide (#12) we see a detailed view of the environment of the Np atoms in $\text{LiCo}(\text{NH}_3)_6\text{Np}_2\text{O}_8(\text{OH})_2 \cdot 2\text{H}_2\text{O}$. First of all, rather than being stabilized by a linear arrangement of oxygens, as in neptunyl or uranyl ion, the Np(VII) is seen to be stabilized by four oxygens which are strongly bonded, the bond lengths being about $1.9\text{\AA}$. Furthermore alternate neptuniums are connected to ~~two~~ two OH groups that have bond lengths of about $2.35\text{\AA}$. The lengths compare to a uranyl bond length of $1.82\text{\AA}$ in $\text{UO}_2(\text{OH})_2$, which shows a U-OH bond length of $2.36\text{\AA}$. In the next slide (#'s 13 & 14) we see the contents of a unit cell with the chain along the c axis formed by the square planar bonded neptunium linked by oxygen bonds at right angles to each plane. Opposite the centrally placed neptunium is a lithium atom which appears in an almost mirror-like configuration. The two oxygens below the Li, however, belong to the two waters of hydration. The other octahedral units which you see sprinkled around are the hexaminocobalt groups which serve to hold the chain together.

It is worthwhile pointing out that U(VI) will place itself in an analogous configuration as shown in the structure of Li_4UO_5 in the next slide (#15), from the work of Hoekstra and Siegel. The four short bonds of $1.99\text{\AA}$ compare to the 1.85 to $1.96\text{\AA}$ found in the Np compound. The octahedrally coordinated Np in this structure leads John Burns and his co-workers Willis Balawin and Jim Stokely to suggest that Np(VII) is probably octahedrally coordinated as well in the compounds prepared by Spitsyn and co-workers. They would thus suggest,

Furthermore, they suggest on the same basis that the correct formulation of the neptunium seven complex ion in solution is

Another area we are beginning to develop at Oak Ridge is the application of photoelectron spectroscopy to problems in the atomic and solid state physics of the actinides. Manfred Krause and his co-workers are carrying out this development. As you remember (next slide) ^{#17} in the application of photoelectron spectroscopy to chemical problems the usual approach is to have an x-ray source of known energy which knocks out an electron from an element or compound under study. The energy of the electron knocked out of the sample, called the converter, is then measured by the spectrometer. Since $h\nu$ is known and $e(\text{photo})$ is measured, the binding energy of the electron in the atom can be obtained by difference. Another approach, however, is to have an unknown x-ray source and a known converter, and then the photoelectron spectrometer becomes a broad range, high resolution x-ray spectrometer (next slide) ^{#18}. For example, one might put a holmium target in the x-ray generator and have neon gas as the converter atom. By measuring $e(\text{photo})$ of a 1s neon electron, for example, the $h\nu$ can be obtained by difference from the known 1s binding energy. An application by Krause to the study of the 4f electrons in holmium is shown in the next slide. ^{#19} The bottom two spectra in this slide, if taken by conventional techniques, would have required two x-ray spectrometers, a grating type and a crystal type because one is around 1400 eV and the other around 150 eV. This would have made it virtually impossible to compare intensities between spectra as has been done here. The most interesting spectrum is the middle one which shows the $4f_{5/2}$ and $4f_{7/2}$ energy levels for comparison with theory, as for example, the theories Len Nugent and Ken Vander Sluis are developing. Krause expects to extend

this type of work to the actinide metals. Work on compounds is also underway, and in the ^{#20}next slide we see the $4f_{5/2}$ and $4f_{7/2}$ electron levels of Am in AmF_3 and also we see the $5f_{5/2}$ level in the less than half-filled shell. These spectra are ordinary ESCA spectra rather than x-ray. Here again, by measuring these levels as a function of Z in the actinide series, Krause hopes to obtain data of importance to theoretical developments such as Nugent's.

Rel HFS Cu, Ag, Au, III

Element	Config	Energy (eV)	
Cu	$3d^{10} 4s^1$	10.1	$3d_{3/2}^{(4)} (d_{3/2} - s_{3/2})$
		9.8	$3d_{5/2}^{(6)}$
		7.1	$4s_{1/2}^{(1)}$
		} <u>2.7</u>	
Ag	$4d^{10} 5s^1$	12.5	$4d_{3/2}^{(4)}$
		11.8	$4d_{5/2}^{(6)}$
		6.9	$5s_{1/2}^{(1)}$
		} <u>4.9</u>	
Au	$5d^{10} 6s^1$	12.2	$5d_{3/2}^{(4)}$
		10.4	$5d_{5/2}^{(6)}$
		8.4	$6s_{1/2}^{(1)}$
		} <u>2.0</u>	
III	$6d^9 7s^2$	13.4	$6d_{3/2}^{(4)}$
		11.7	$7s_{1/2}^{(2)}$
		10.1	$6d_{5/2}^{(5)}$
		} <u>-1.6</u>	

Rel HFS Cu, Ag, Au, 111

ment	Config	Energy (eV)	
u	$3d^{10} 4s^1$	10.1	$3d_{3/2}^{(4)} (d_{3/2}-s_{1/2})$
		9.8	$3d_{5/2}^{(6)}$
		7.1	$4s_{1/2}^{(1)}$
			} <u>2.7</u>
d	$4d^{10} 5s^1$	12.5	$4d_{3/2}^{(4)}$
		11.8	$4d_{5/2}^{(6)}$
		6.9	$5s_{1/2}^{(1)}$
			} <u>4.9</u>
.	$5d^{10} 6s^1$	12.2	$5d_{3/2}^{(4)}$
		10.4	$5d_{5/2}^{(6)}$
		8.4	$6s_{1/2}^{(1)}$
			} <u>2.0</u>
.	$6d^9 7s^2$	13.4	$6d_{3/2}^{(4)}$
		11.7	$7s_{1/2}^{(2)}$
		10.1	$6d_{5/2}^{(5)}$
			} <u>-1.6</u>

Promition Energies (in eV)

	Cu ⁺	Ag ⁺	Au ⁺	111 ⁺	Au ⁰	111 ⁰
d-s						
Calc.	2.9	4.6(4.6)	1.6(1.6)	-2.1(-2.0)	(0.8)	(2.7)
Exp.	2.7	4.8	1.9	—	—	—

			4.6(d ² -d ¹ p)		
d-p					
Calc.	8.8	9.9(9.8)	7.0(7.7)	(5.9)(d ⁵ -d ³ p)	(5.9)
Exp.	8.2	9.9	7.8	—	—

s-p					
Calc.	5.9	5.3(5.2)	5.4(6.1)	7.1(7.9)	(5.1)
Exp.	5.5	5.1	5.9	—	—

Calculated Values from relativistic HFS [Carlson, Nestor, Fricke]
 Experimental Values from J.D. Punitz and L.E. Orgel,
 Adv. Inorg. and Radiochem. 2, 1 (1960)

Slide 7

ORNL-DWG 72-8028

$\text{ThO}_2: 249\text{Bk}^{4+}$
 $\nu_e = 9.459\text{ GHz}$
 $T \sim 1.5\text{ K}$

Slide 8

PHOTO 95588

$T = 1.5^\circ\text{K}$

$\nu_0 = 9\text{GHz}$

50 gauss

ESR Spectrum of Cm^{3+} and Am^{2+} in SrCl_2 Showing ^{245}Cm Hyperfine Structure and Two of the Six ^{243}Am Hyperfine Lines.

Slide 9

Schematic of NP(O)_3^{3-} Ion
(Spitsyn et al JINC 31, 2735 (1969)).

Slide 10

Slide 12

ORNL-DWG. 72-3322

Slide 13

ORNL-DWG. 72-3325

Slide 14

ORNL-DWG. 72-3328

Slide 15

Bi-pyramidal Structure of $Ni(III)$ Complex
Suggested by Burns, Baldwin, and Stetley

Slide 16

ORNL-DWG. 72-8454

X-RAY SOURCE

CONVERTER ATOM

ENERGY ANALYZER

Slide 17

ORNL - DWG. 72-8454

X-RAY SOURCE

Holmium

CONVERTER ATOM

Neon 1s 870eV
2p 22eV

ENERGY ANALYZER

Slide 18