Why Gold and Copper Are Colored but Silver Is Not

Ariel H. Guerrero,* Héctor J. Fasoli, and José Luis Costa**
Facultad de Ciencia y Tecnología, Universidad del Salvador, Santa Fe 2874, 1425 Buenos Aires, Argentina

It is well known that 80% of chemical elements are metals. When polished, all metals shine owing to reflection of photons by external valence electrons dynamically forming metallic bonds (*1*). White light reflects on most metals without color absorption or change to the naked eye; but copper and gold are yellow because they absorb "blue" and "red" photons by electron transitions between spectromeric configurations $ns^1(n-1)d^{10} \leftrightarrow ns^2(n-1)d^9$ of external sublevels (*2*).

The next question is why silver, with the same external electronic configuration as copper and gold (group 11, IB), is not yellow. The answer is simple, considering atomic radii, ionization potentials and nuclear charge:

	Cu	Ag	Au
Atomic radius / pm	117.3	133.9	133.6
1st ionization energy / eV	7.725	7.576	9.22
2nd ionization energy / eV	20.29	21.48	20.52
Nuclear charge	25	35	59

All values taken from ref *3*.

The atomic radius of silver is 16.6 pm larger than that of copper, allowing a bigger difference between sublevels s and d, which is sufficient to restrict the transition $s^1d^{10} \leftrightarrow s^2d^9$ to a lower probability. This is equally supported by the first ionization energy: since it is lower in silver, the fact that one external electron is ejected more easily than in copper atoms is justified.

With their higher nuclear charge (35 vs 25) silver atoms also have larger radii (Δ = 16.6 pm), and the distance between external sublevels—both spatial and energetic—is too large to freely allow s $\leftrightarrow$ d transitions. However, the distance is not large enough to prevent the transitions completely, and after several reflections on two parallel silver mirrors, white light becomes pale yellow (*4*).

Now we must face an unexpected problem: why is gold yellow? According to the same line of reasoning, gold would be colorless if it had bigger atoms. But gold atoms are *not* larger than silver; the radii of silver and gold are practically identical owing to lanthanide contraction (*3*, *5*). Comparing ionization energies, the value 9.22 eV for gold is about 20% higher than 7.576 eV for silver because gold has a larger nuclear charge (59 vs 35) while its radius is practically the same. Thus, external s and d sublevels are close enough to allow the necessary transition. As a result, the probability of transition between sublevels is similar to that of copper, and gold is again yellow.

We can now perceive the necessary conditions for a metal to be yellow, like copper and gold (*2*):

1. Adequate external electronic configuration $s^1d^{10} \leftrightarrow s^2d^9$ (group 11, IB).
2. Sublevels s and d close enough to allow transition $s^1d^{10} \leftrightarrow s^2d^9$ to occur significantly (Cu, Au).

In contrast, all other metals shine silvery, colorless to the naked eye because they do not possess the necessary electronic external configuration and transition probability to appear colored.

Much work has been undertaken in connection with relativistic effects on metal properties (*6*); however a final question remains: are metals (except for Cu and Au) really colorless? Various tinges are reported, such as yellow for silver and blue for osmium. How many more will be detected when a complete survey is made? What number of atomic layers must be crossed (twice) in metals to produce a definite color? What about the effect of atomic packing, holes, and impurities? But this is another story and we would be very happy if research is aroused and enhanced by our questions.

Literature Cited

1. Steiner, L. E.; Campbell, J. A. *General Chemistry*; McMillan: New York, 1955.
2. Guerrero, A. H.; Fasoli, H. J.; Costa, J. L.; Piccardo, S. V. de. *J. Chem. Educ.* 1989, *66*, 400.
3. Shriver, D. F.; Atkins, P. W.; Langford, C. H. *Inorganic Chemistry*; Oxford University Press: Oxford, 1996.
4. Mellor, J. W. *Mellor's Modern Inorganic Chemistry*, 6th ed.; Revised and edited by Parkes, G. D.; Wiley: New York, 1967; Chapter 26, Section 17.
5. Huheey, J. E. *Inorganic Chemistry*; Harper & Row: New York, 1978.
6. Pyykkö, P. *Chem. Rev.* 1988, *88*, 563.

*Corresponding author.
**Also Escuela Superior Técnica del Ejército, Buenos Aires.