

# **The Science and Engineering of Materials:**

## **Chapter 2 Exercises**

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**Skills Learned:** Unit conversion, fundamental constants of elements

**Knovel Problems:**

K2-1 A 2 in.-thick steel disk with an 80 in. diameter has been plated with a 0.0009 in. layer of zinc.

- (a) What is the area of plating in  $\text{in}^2$ ?
- (b) What is the weight of zinc required in lb?
- (c) How many moles of zinc are required?
- (d) Name a few different methods used for zinc deposition on a steel substrate.
- (e) Which method should be selected in this case?

### Knovel Solutions:

- (a) Search for 'cylinder surface area' on Knovel. In the search results, click on the text link for the *Appendix G: Geometric Formulas* in the title *Aerosol Measurement – Principles, Techniques, and Applications (2nd Edition)* (John Wiley & Sons © 2001) to see the formula for calculating the surface area of a cylinder:

Ellipsoids: oblate

surface area

$$= 2\pi a^2 + \frac{\pi b^2}{\varepsilon} \ln\left(\frac{1+\varepsilon}{1-\varepsilon}\right)$$

volume

$$= \frac{4\pi a^2 b}{3}$$

Right cylinder

surface area

$$= 2\pi rL + 2\pi r^2 = \pi dL + \frac{\pi d^2}{2}$$

where L is the length

volume

$$= \pi r^2 L = \frac{\pi d^2 L}{4}$$

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$$A = (\pi \cdot d \cdot L) + \left(\frac{\pi \cdot d^2}{2}\right)$$

$$A = \left(\pi \cdot \frac{10000}{127} \cdot \frac{250}{127}\right) + \left(\frac{\pi \cdot \left(\frac{10000}{127}\right)^2}{2}\right) = 10225.90454 \text{ in}^2$$

- (b) Search for 'zinc plating weight' on Knovel. In the search results, click on the text link for the section 63.28.1 *Calculation Procedure* in the title *Standard Handbook of Engineering Calculations (4th Edition)* (McGraw-Hill © 2005). The text below provides the equation for calculating the weight of plating metal and the density of zinc:

2. *Compute the weight of metal required.* The plating metal weight = (area plated, in<sup>2</sup>) (plating thickness, in) (plating metal density, lb/in<sup>3</sup>). For this plating job, given the density of zinc from Table 11, the plating metal weight = (60 × 144)(0.004)(0.258) = 8.91 lb (4.0 kg) of zinc. In this calculation the value 144 is used to convert 60 ft<sup>2</sup> to square inches.

**Related Calculations** The efficiency of finishing cathodes is high, ranging from 80 to nearly 100 percent. Where the actual efficiency is unknown, assume a value of 80 percent and the results obtained will be safe for most situations.

**TABLE 11** Electroplating Current and Metal Weight

Metal	Time to deposit, Ah		Metal density	
	0.001 in/ft <sup>2</sup> at 100% efficiency	0.01 mm/m <sup>2</sup> at 100% efficiency	lb/in <sup>3</sup>	g/cm <sup>3</sup>
Antimony, Sb	10.40	0.038	0.241	6.671
Cadmium, Cd	9.73	0.036	0.312	8.636
Chromium, Cr	51.80	0.189	0.256	7.086
Cobalt(ous), Co	19.00	0.069	0.322	8.913
Copper(ous), Cu	8.89	0.033	0.322	8.913
Copper(ic), Cu	17.80	0.065	0.322	8.913
Gold(ous), Au	6.20	0.023	0.697	19.29
Gold(ic), Au	18.60	0.068	0.697	19.29
Nickel, Ni	19.00	0.069	0.322	8.913
Platinum	27.80	0.102	0.775	21.45
Silver, Ag	6.20	0.023	0.380	10.52
Tin(ous), Sn	7.80	0.029	0.264	7.307
Tin(ic), Sn	15.60	0.057	0.264	7.307
Zinc, Zn	14.30	0.052	0.258	7.141

$$M = A \cdot t \cdot \rho = 10225.90454 \cdot \frac{9}{10160} \cdot 0.258 = 2.337062041 \text{ lb}$$

- (c) To obtain the number of moles required, we must first find the molar mass of zinc. Go to the Periodic Table (Tools menu) and find zinc (atomic no. 30):

Periodic Table

Color Config Usage

1 H Hydrogen 1.00794																	2 He Helium 4.002602																						
3 Li Lithium 6.941	4 Be Beryllium 9.012182																																						
5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.00644	8 O Oxygen 15.999	9 F Fluorine 18.998403	10 Ne Neon 20.1797																																		
11 Na Sodium 22.98976928	12 Mg Magnesium 24.304																																						
13 Al Aluminum 26.9815385	14 Si Silicon 28.08558	15 P Phosphorus 30.9737615	16 S Sulfur 32.06	17 Cl Chlorine 35.453	18 Ar Argon 39.948																																		
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955912	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.99616	25 Mn Manganese 54.938044	26 Fe Iron 55.845	27 Co Cobalt 58.933195	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.630	33 As Arsenic 74.9216	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798																						
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90584	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium 98.90625	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.9055	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.757	52 Te Tellurium 127.6	53 I Iodine 126.905	54 Xe Xenon 131.29																						
55 Cs Cesium 132.90545	56 Ba Barium 137.327	57 La Lanthanum 138.90547	58 Ce Cerium 140.12	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.242	61 Pm Promethium 144.9126	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92532	66 Dy Dysprosium 162.50014	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93032	70 Yb Ytterbium 173.05468																								
87 Fr Francium 223	88 Ra Radium 226	103 Lr Lawrencium 260	104 Rf Rutherfordium 261	105 Db Dubnium 262	106 Sg Seaborgium 266	107 Bh Bohrium 264	108 Hs Hassium 277	109 Mt Meitnerium 268	110 Ds Darmstadtium 271	111 Rg Roentgenium 272																													
<div><div>Zn [Ar]3d104s2</div><div></div></div>												<div><div>Standard Electron Orbital Configuration</div><div></div></div>																											
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The molar mass of zinc is 0.1441602637 lb/mol. The number of moles is calculated as:

$$\text{Number of moles} = \frac{\text{mass}}{\text{Molar mass}} = \frac{2.337062041}{0.1441602637} = 16.21155498 \text{ mols of Zinc}$$

- (d) Search for 'zinc application methods' on Knovel. In the search results, click on the text link for the section *13.4 Zinc Coatings* in the title *Corrosion (3rd Edition) Volumes 1-2* (Elsevier © 1994):

### **Methods of Application**

The principal method for applying zinc coatings to iron and steel is hot-dip galvanising. There are four other important methods, each of which has its own particular applications; these methods are spraying, plating, sherardising and painting with zinc-rich paints. The choice of method in any given case is determined by the application envisaged, and the five processes may be said to be complementary rather than competitive, for there is usually little doubt as to which is the best for any particular purpose. Processes of applying coatings by various methods are discussed in detail elsewhere<sup>1</sup> and are considered in Chapter 12, and will not, therefore be considered here. The reactions inherent in galvanising tend to ensure a thick and even coating but guides to the inspection of galvanising, sherardising and zinc spraying are available<sup>2</sup>.

The deposition methods for Zn are hot-dip galvanizing, spraying, plating, sherardising, and painting with zinc-rich paints.

- (e) Search for 'zinc coatings comparison' on Knovel. In the search results, click on the text link for the section 13.4 Zinc Coatings in the title *Corrosion (3rd Edition) Volumes 1-2*:

**Table 13.7** Comparison of zinc coatings

Characteristics of coating	Hot-dip galvanising	Metal spraying	Plating	Sherardising	Zinc dust painting
1. Process considerations	Parts up to 20 m long and fabrications of 18 m × 2 m × 5 m can be treated. Care required at design stage for best results. Continuous galvanised wire and strip up to 1.4 m wide) in UK	No size or shape limitations. Access difficulties may limit its application, e.g. inside of tubes. Best method for applying very thick coatings. Little heating of the steel	Size of bath available. Process normally used for simple, fairly small components suitable for barrel plating or for continuous sheet and wire. No heating involved	Batch processing is mainly suitable for fairly small complex components. Semi-continuous process for rods, etc.	Can be brush, spray or dip applied on site when necessary. No heating involved. Performance varies with media used
2. Economics	Generally the most economic method of applying metallic zinc coatings 20–200 µm thick	Most economic for work with high weight to area ratio. Uneconomic on open mesh	Used, where a very thin zinc coating is sufficient. Thick coatings are expensive.	More expensive than galvanising for equivalent thicknesses. Generally used when control of tolerances is more important than thickness of coating	Low overheads but high labour element in total cost as with all paints. Thixotropic coatings reduce number of coats and hence labour costs
3. Adhesion	Process produces iron–zinc alloy layers, overcoated with zinc; thus coating integral with steel	Good mechanical interlocking provided the abrasive grit-blasting pretreatment is done correctly	Good, comparable with other electroplated coatings	Good—the diffused iron–zinc alloy coating provides a chemical bond	Good—abrasive grit blasting preparation of the steel gives best results
4. Thickness and uniformity	Normally about 75–125 µm on products, 25 µm on sheet. Coatings up to 250 µm on products by prior grit-blasting. Very uniform—any discontinuities due to poor preparation of the steel are readily visible as 'black spots'	Thickness variable at will, generally 100–200 µm but coatings up to 250 µm or more can be applied. Uniformity depends on operator skill. Coatings are porous but pores soon fill with zinc corrosion products; thereafter impermeable	Thickness variable at will generally 2–25 µm. Thicker layers are possible but generally uneconomic. Uniform coating within limitations of 'throwing power' of bath. Pores not a problem as exposed steel protected by adjacent zinc	Usually about 12–40 µm closely controlled. Thicker coatings also possible. Continuous and very uniform even on threaded and irregular parts	Up to 40 µm of paint (and more with special formulations) can be applied in one coat. Good uniformity—any pores fill with reaction products

Reviewing the above table, we find that the plating is preferred for the steel substrate of given geometry and required coating thickness.