

# MTS723F97 Homework 4 Solution J. J. Weimer 23.Nov.97

Constants

> kb := 1.3806e-23: JpeV := 1.602e-19:

## Problem 1

The Richardson equation is

$$> JR := AR (1 - rz) T^2 e^{\left(-\frac{\phi}{kbT}\right)}$$

$$JR := AR (1 - rz) T^2 e^{\left(-.7243227582 \cdot 10^{23} \frac{\phi}{T}\right)}$$

### part a

The relevant parameters for this equation are

> rz := 0: AR := 120:

> JRA := evalf(subs(T=(2500+273.15),phi=2.5\*JpeV,JR),4);

$$JRA := 26450.$$

The theoretical maximum current density is 26,500 A/cm<sup>2</sup>

### part b

> JRB := evalf(subs([T=(2500+273.15),phi=4.0\*JpeV],JR),4);

$$JRB := 49.55$$

The current density for a work function of 4.0 eV is about 50 A/cm<sup>2</sup>

> ratio := JRA/JRB;

$$ratio := 533.8042381$$

The current density decreases by a factor of 533

The easiest way to find the new temperature is to find the roots of the following equation

> currentdensity := JRA - subs(phi=4.0\*JpeV,JR) = 0;

$$currentdensity := 26450. - 120 T^2 e^{\left(-\frac{46414.60235}{T}\right)} = 0$$

> solve(currentdensity,T);

$$3391.202289 - 1647.153574 I, 4124.347016$$

The temperature to reach the same current density is about 4120 K or 3850 oC.

The melting temperature of W is 3410 oC, so we will never reach the same current density of a clean W filament if it becomes coated with C.

## Problem 2

This is done separately because it involves pictures to show the proper relationships.

### Problem 3

Given Design Parameters

> delalpha := 5: alpha := 42.308:  
clearance := 10.0:

#### part a

Let's design the CMA assuming a wall thickness of 1 mm and a clearance of 2 mm all around to fit through the flange. Let's also add a margin of 2 mm to the point where the electrons reach their maximum travel (so they do not hit the outer wall). This means the maximum off-axis distance reached by the electrons will be

> rmax := clearance - 0.1 - 0.2 - 0.2;

$$rmax := 9.5$$

and the outer radius will be

> ro := clearance - 0.1 - 0.2;

$$ro := 9.7$$

We can now find the inner radius.

> ri := rmax/exp(1.3099\*(sin((alpha + delalpha)\*Pi/180)^2));

$$ri := \frac{9.5}{e^{(1.3099 \sin(.2628222222 \pi)^2)}}$$

> evalf(ri,4);

$$4.683$$

The distance from sample position to focal point is

> focallength := evalf(6.130\*ri,4);

$$focallength := 28.71$$

ri = 4.68 cm, ro = 9.7 cm (to inside of outer wall), focal length = 28.7 cm

#### part b

The best relative resolution we can expect is

> relresolution := evalf(2.75\*(delalpha\*Pi/180)^3,4);

$$relresolution := .001828$$

### part c

The voltage difference needed to focus 500 eV electrons is

```
> delV := 500*ln(ro/ri)/1.3099: evalf(",4);
```

278.1

## Problem 4

### part a

The spectra are labelled separately

### part b

The source for all the spectra is Mg.

Spectrum A has an obvious ghost peak due from F 1s at about 460 eV. It is from Al radiation.

The separation between Mg and Al radiation lines is 233 eV.

Actually, all of the spectra but Sample B have noticeable ghost peaks if you look closely enough.

### part c

The separation between the main peak and first satellite for Mg was measured using a millimeter ruler. The value was found to be (in eV)

```
> satsep := evalf(18*10/21,3);
```

*satsep := 8.57*

The measured full width half maximum of the peak was found using a millimeter ruler to be (in eV)

```
> mFWHM := evalf(6.5*10/21,3);
```

*mFWHM := 3.10*

The line broadening introduced by source and analyzer can be found from the formulation (where m, t, a, and s mean measured, true, analyzer, and source, respectively)

$$mFWHM^2 = tFWHM^2 + aFWHM^2 + sFWHM^2$$

```
> spaFWHM := sqrt(mFWHM^2 - 0.5^2);
```

*spaFWHM := 3.059411708*

The line broadening due to the Mg source is 0.7 eV. Therefore, the analyzer broadening is (in eV)

```
> aFWHM := sqrt(spaFWHM^2 - 0.7^2);
```

*aFWHM := 2.978254522*

(This information was NOT given. It illustrates further principles that could be applied.)

The spectrum was taken at a pass energy of 89.5 eV. The relative resolution of the analyzer was therefore

```
> relresolution := aFWHM/89.5;
```

```
relresolution := .03327658685
```

## ▣ Problem 5

### ▣ part a

The FWHM of the three principal peaks were measured using a millimeter ruler

```
> FWHMO := evalf(28*2/38.5,3);  
FWHMTi := evalf(11.5*5/47,3);  
FWHMC := evalf(18*2/29.5,3);
```

```
FWHMO := 1.45
```

```
FWHMTi := 1.22
```

```
FWHMC := 1.22
```

The absolute resolutions for the Ti and C peaks are clearly equal based on their FWHM values. The FWHM for the O peak is not a good indicator of absolute resolution because it clearly is distorted by the overlapping shoulder at higher binding energy.

The relative resolutions are given according to the KINETIC ENERGY of the electrons. The source is Mg with an energy of 1253.6 eV. Assume a work function of zero eV (it is actually about 4 eV for this system).

```
> relrO := FWHMO/(1253.6 - 531);  
relrTi := FWHMTi/(1254.6 - 458);  
relrC := FWHMC/(1253.6 - 286);
```

```
relrO := .002006642679
```

```
relrTi := .001531508912
```

```
relrC := .001260851591
```

The relative resolutions clearly decrease as the kinetic energy of the peaks increases.

## part b

The peak heights were measured using a millimeter ruler. The shoulder to the O 1s peak is included as though it is a separate peak. O1 is the lower binding energy peak. Only the Ti 2p<sub>3/2</sub> peak is used. The peak heights are (in c/s)

```
> phO1 := evalf(115*1000/70);  
  phO2 := evalf(39*1000/70);  
  phTi := evalf(116*1000/63.5);  
  phC := evalf(116*500/122.5);
```

*phO1 := 1642.857143*

*phO2 := 557.1428571*

*phTi := 1826.771654*

*phC := 473.4693878*

The sensitivity factors we need are

```
> SO := 0.711: STi := 2.001: STi32 := 1.334: SC := 0.296:
```

Find the atomic concentrations.

```
> AllPeaks := phO1/SO + phO2/SO + phTi/STi32 + phC/SC;
```

*AllPeaks := 6063.186260*

```
> xphO1 := (phO1/SO)/AllPeaks;  
  xphO2 := (phO2/SO)/AllPeaks;  
  xphTi := (phTi/STi32)/AllPeaks;  
  xphC := (phC/SC)/AllPeaks;
```

*xphO1 := .3810915241*

*xphO2 := .1292397343*

*xphTi := .2258538637*

*xphC := .2638148779*

Based on peak heights, the sample has

38 % O1, 13 % O2, 23 % Ti, and 26 % C

### part c

The areas read from the integrated curves are (in eV c/s)

> aO1 := 2350: aO2 := 1150: aTi := 4120: aC := 770:

> AllPeaksA := aO1/SO + aO2/SO + aTi/STi + aC/SC;

*AllPeaksA := 9582.966029*

> xaO1 := (aO1/SO)/AllPeaksA;

xaO2 := (aO2/SO)/AllPeaksA;

xaTi := (aTi/STi)/AllPeaksA;

xaC := (aC/SC)/AllPeaksA;

*xaO1 := .3449040650*

*xaO2 := .1687828403*

*xaTi := .2148573321*

*xaC := .2714557626*

Based on peak areas, the sample has

34 % O1, 17 % O2, 21 % Ti, and 27 % C

### part d

If the peak is a Gaussian or Lorentzian shape with no interfering shoulders, then its peak height is exactly proportional to its peak area. Anytime a shoulder or asymmetric peak appears, calculations using peak heights will be wrong if the sensitivity factor for peak area is used. If you have access to sensitivity factors based on peak heights and on peak areas, you can tell whether a peak will be a symmetric shape (Gaussian or Lorentzian). The sensitivity factor based on height and area will be equal.

### part e

The sample appears to have a peak for Ti metal at about 452 eV. It is very small. The evidence for sub-oxides of Ti would show as a peak to the right (low binding energy) side of the principal peak at 458 eV. Without careful comparison to reference spectra for TiO<sub>2</sub> or careful peak fitting analysis, we cannot resolve how much of a contribution is made by a separate peak for titanium sub-oxides.

## part f

The O peak at higher binding energy is from  $\text{TiO}_x$ . Using the peak heights or peak areas, the ratio of O/Ti appears to be about 1.6 - 1.7. We should actually decrease the Ti peak area by the amount of Ti and suboxide to find out whether the  $\text{TiO}_2$  is really from  $\text{TiO}_2$ . A calculation taking this into account gives the following:

>  $\text{OtTiRatio} := (\text{aO1}/\text{SO})/((\text{aTi} - 300)/\text{STi});$

*OtTiRatio* := 1.731338502

The sample still appears to be less than stoichiometric  $\text{TiO}_2$ .