FINAL EXAM

MSEG 302 Spring 2018

Materials Science and Engineering
The University of Delaware

May 17th, 2018

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Name: Key

Honor Pledge:

"I have neither given nor received aid on this examination, nor have I witnessed any one else giving or receiving such assistance".

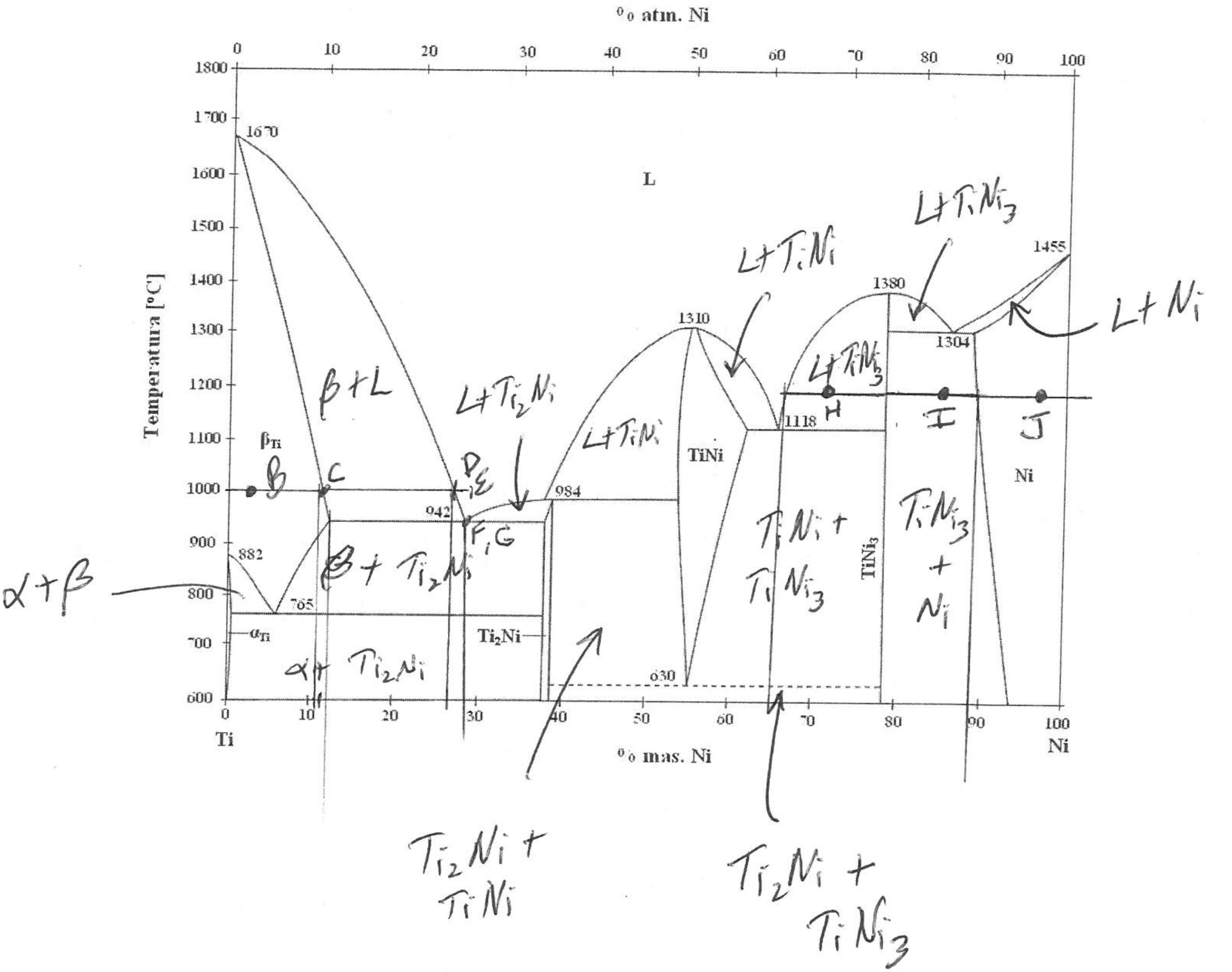
Sign here only if true: DCM

Potentially useful information:

Avogadro's number: Nav 6.02×10^{23} molecules/mol
Boltzmann's constant: k 1.38×10^{-23} J/atom-K
Gas constant: R 8.314 J/mol-K
Electron charge: e 1.602×10^{-19} C
1 MPa = 145 psi
g = Acceleration of gravity: 9.8 m/sec^2
1 N = 1 kg m/sec^2

	Q1	Q2	Q3	Q4	Q5	Q6	TOT
$\bar{x}$	15	16	15	9	29	7	91
σ	5	5	5	4	5	4	18
Max	25	26	24	12	32	12	125
Min	0	0	0	0	0	0	38

1. The following figure shows the phase diagram for a binary mixture of titanium (Ti) and nickel (Ni). The atomic percents are shown at the top, and the mass (weight) percents at the bottom of the figure.



14

7 total (0,5 each)

a) The single phase regions are all labeled in this diagram. Label all of the two-phase regions with the phases present in each case.

See figure – 14 such 2ϕ regions

b) What would be the phase or phases present in a mixture of 2 grams of nickel with 48 grams of titanium at 1000 C? β_{Ti}, 4 wt% Ni

c) How much additional nickel (in grams) would have to be added to this alloy in order for it to start to form liquid at 1000 C? $x \sim 4$ grams

d) What would be composition of the first liquid that starts to form as nickel is added to this alloy? 26 wt% Ni

e) How much additional nickel (in grams) would have to be added to the original alloy to convert it entirely to liquid? 14.9 grams (from b), or 10.4 grams (from c)

f) What is the composition and melting point of the titanium-nickel alloy with the lowest melting point? 28 wt% Ni, $T_m = 942°C$

g) What are the compositions and relative amounts of the first phase or phases formed when this lowest melting point alloy is cooled from the liquid into a solid?

37 wt% (β_{Ti}, 12 wt% Ni), 63 wt% (Ti_2Ni, 38 wt% Ni)

h) 35 grams of nickel is mixed with 15 grams of titanium and held at 1200 C. What are compositions and relative amounts of the phases present?

60 wt% (L, 65 wt% Ni), 40 wt% ($TiNi_3$, 78 wt% Ni)

i) 50 grams of additional nickel is added to the alloy from part h. What are the compositions and relative amounts of the phases present at 1200 C for this new mixture?

60 wt% (Ni, 88 wt% Ni), 40 wt% ($TiNi_3$, 78 wt% Ni)

j) 200 grams of additional nickel is added to the alloy from part i. What are the compositions and relative amounts of the phases present at 1200 C for this new mixture?

95 wt% Ni (100%)

2. Enclosed is the phase diagram for iron and carbon.

a) At what temperature does pure BCC iron first transform to FCC iron on heating? 912°C

b) At what temperature does pure FCC iron transform back to BCC iron on heating? 1394 °C

c) At what temperature does pure iron melt into a liquid? 1538°C

d) What is the maximum concentration of carbon possible in the FCC phase of iron before causing precipitation of either Fe_3C or liquid? 2.14 wt%

e) At what temperature is the carbon solubility in FCC iron a maximum? 1147°C

f) What is the lowest melting temperature of any iron-carbon alloy? 1147°C

g) What is the composition of the iron-carbon alloy with the lowest melting temperature? 4.3 wt% C

h) The composition of an iron-carbon alloy is to be adjusted so that it will be precisely 50% liquid and 50% solid by weight at 1300 C. What is the required composition? ~2.16 wt% C

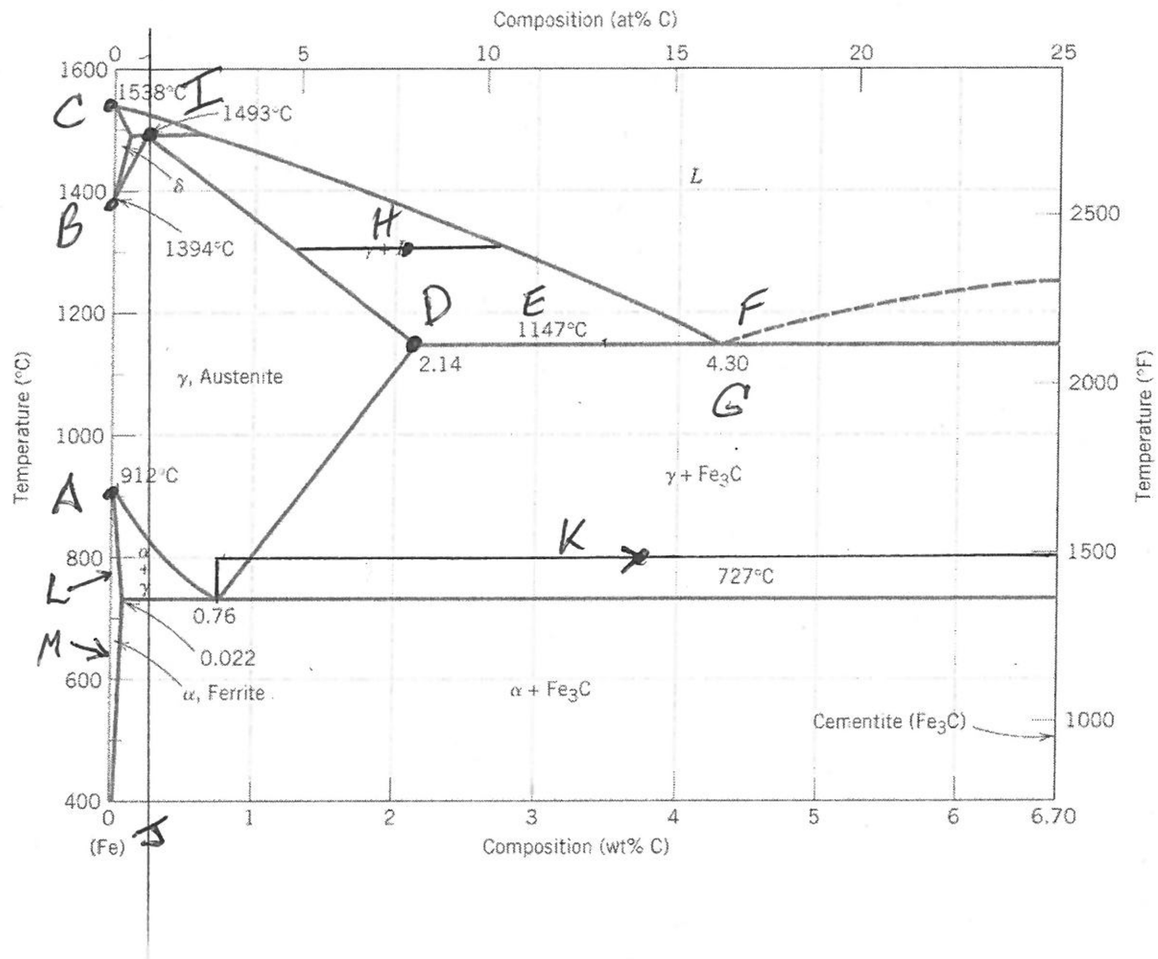
i) What is the highest temperature at which an iron-carbon alloy is stable as a single phase FCC solid solution? 1493°C

j) What is the composition of this FCC iron-carbon alloy that is stable as a single phase at the highest temperature? ~0.23 wt% C

k) A 1 kg sample of an iron-carbon alloy with the eutectoid composition is heated to 800 C. Carbon is then added at constant temperature until the sample is precisely 50% austenite and 50% cementite. How much carbon was added? ~32 grams

l) For a hypoeutectoid steel, does the carbon solubility in ferrite increase, decrease, or remain the same when the sample is heated at temperatures just above the eutectoid temperature (727 C)? decrease

m) For a hypereutectoid steel, does the carbon solubility in ferrite increase, decrease, or remain the same when the sample is cooled at temperatures just below the eutectoid temperature (727 C)? decrease


Composition (at% C)
0
5
10
15
20
25
1600
1400
1200
1000
800
600
400
1538°C
1493°C
1394°C
912°C
L
δ
γ + L
γ, Austenite
1147°C
2.14
4.30
γ + Fe3C
727°C
0.76
0.022
α + γ
α, Ferrite
α + Fe3C
Cementite (Fe3C)
2500
2000
1500
1000
Temperature (°C)
Temperature (°F)
0
1
2
3
4
5
6
6.70
(Fe)
Composition (wt% C)
A
B
C
D
E
F
G
H
I
J
K
L
M

3a. The temperature dependence the conductivity of a certain intrinsic semiconductor is known to vary as:

$$\sigma = \sigma_0 \exp\left(-\frac{E_g}{kT}\right)$$

where E_g is the band gap, k is Boltzmann's constant and T is the absolute temperature.

The conductivity of a sample of this intrinsic semiconductor triples when the temperature is raised from 25° C to 60° C. Calculate the band gap E_g of this material in either kJ/mol or eV.

E_g = 43.2 kJ/mole

3b. If silicon single crystals were doped with small amounts of boron, what are the most likely outcomes?

a) the conductivity would a) increase, b) decrease, c) stay about the same.

b) the number of p-type carriers would a) increase, b) decrease, c) stay about the same.

c) the number of n-type carriers would a) increase, b) decrease, c) stay about the same

3c. Calculate the conductivity of the intrinsic semiconductor germanium from the following characteristics:

carrier density (where # holes= # electrons):	2.4×10^{19}	carriers/m^3
electron mobility:	0.39	m^2/(volt sec)
hole mobility:	0.19	m^2/(volt sec)
charge/electron = charge/hole	1.6×10^{-19}	coulombs/carrier

$$\sigma = ne\mu_e + pe\mu_h \simeq 2 \ (\Omega \cdot m)^{-1}$$

3d. In an experiment on an n-doped sample of germanium, it is found that the resistivity is 1×10^{-5} ohm m. What is the carrier density in this sample?

$$\rho = 1 \times 10^{-5}$$

$$\sigma = \frac{1}{\rho} \cong ne\mu_e \quad \therefore \quad n = \frac{\sigma}{e\mu_e} \cong 1.6 \times 10^{24} \frac{}{m^3}$$

4. Poly(isoprene) has a repeat unit with the chemical formula C_5H_8. The crystal unit cell for poly(isoprene) is orthorhombic, with dimensions a=1.24 nm, b=0.89 nm, and c=0.81 nm. The theoretical density of these poly(isoprene) crystals is 1.0 gm/cm^3. How many poly(isoprene) repeat units are there in each unit cell?

$M_0 = 68.12$ g/mol
for C_5H_8

$$\rho = \frac{n \cdot M_0}{V_{uc} N_{av}}$$

$$V_{uc} = a \cdot b \cdot c$$

solving for n gives ≈ 8

5. For the following materials, describe an object that would be a good candidate for being manufactured from the substance, and name one important physical property that significantly influences this choice.

Item	Object	Property
Silicon single crystal	computer chip	doping to change σ
Carbon-fiber epoxy composite	airplane part	High strength/weight
Plain carbon steel	car frame	toughness, cost
Polyisoprene rubber	rubber band	elongation
Polyethylene	shopping bag	toughness, low ρ
Tungsten carbide	cutting tool	strong, stiff, tough
PPTA (Kevlar) fiber	ballistic fabric	high σ, E, low ρ
MPDI (Nomex) aramid fiber	racing attire	flame resistance
Pyrex (borosilicate) glass	window, beaker	clarity, thermal stab.
GaAs semiconductor	LED	high μ, band gap
Stainless steel	cutlery	corrosion resist.
Concrete	sidewalk	compressive σ, cost
Ni-based superalloy	turbine blade	creep resistance
Barium titanite	actuator	piezoelectricity
Aluminum oxide	abrasive grit	σ, hardness
Copper	wire	conductivity

6. You are asked to consider several different candidate materials in the design of a round, cylindrical shaft that is 2 m long. During operation, the shaft must support a tensile load of 100,000 N. To insure quality and avoid potential failures, you are asked to make sure the applied stress is only 25% of the tensile strength.

Given the data below, estimate the diameter, mass, and total cost for each material.

Data

	ρ	σ_{tens}	c
Materials	Density (gm/cm^3)	Tensile strength (MPa)	Cost ($/kg)
Polyethylene	0.96	25	0.75
Stainless Steel	7.9	900	1.00
Glass	2.5	60	0.10
Carbon-fiber composite	1.5	3000	10.

Results

Material	Diameter (cm)	Mass (kg)	Cost ($)
Polyethylene	14.3	31	23
Stainless Steel	2.4	7.1	7.1
Glass	9.2	33	3.3
Carbon-fiber composite	1.3	0.4	4

$$\therefore d = \left(\frac{4F}{\pi \sigma_{op}}\right)^{1/2}$$

$$\sigma = \frac{F}{A}$$

$$\$ = c \cdot m$$

$$A = \frac{\pi d^2}{4}$$

$$m = \rho \cdot V$$

$$V = \left(\frac{\pi d^2}{4}\right) L$$

$$\sigma_{operate} = \frac{\sigma_{tensile}}{4}$$