

New Program Exam 1 Structure

The Tri-Campus PhD Materials Science Committee has decided to restructure the Program Exam-1 to put the topics covered on the exam more in line with the basic information every practicing Materials Scientist should be familiar with.

The PE-1 exam will consist of three sections:

- Section 1. Structures and Properties;
- Section 2. Characterization and Testing; and
- Section 3. Thermodynamics and Processing.

Each exam will be limited to 2 hours and will consist of two parts, a short answer part and a more detailed essay or problem part. The use of multiple-choice answers in the short answer part should be discouraged because of possible ambiguous answers. Instead a short written answer should be required. The essay/problem portion should offer a broad choice of questions to be answered in order to accommodate students with different backgrounds.

The exam will be given for the first time this October and subsequently will be given every September and February. Every student in the Materials Science PhD Program may take this first exam without penalty should they not pass it. Every new student may also take the first exam offered after they enter the program without penalty. All students in the Materials Science PhD Program will be expected to take all three sections of the exam after their first full year of graduate study in the Program and will have two attempts to pass it. Those students who do well on two of the three sections and fail one section may take just that section at the next offering. Students failing two or more sections must retake the entire exam at the next offering.

A syllabus for each of the sections is provided below for students to use in preparation for the exam and for faculty members preparing the exam. Each question should be referenced back to the syllabus in the master exam file (to assure that questions do not go beyond the syllabus). Campus Coordinators will have a complete set of the required books to loan to students preparing for the exam.

Exam Syllabus

Section 1. Structure and Properties of Materials

Notes

1. These examination topics are covered with varying degrees of detail in many introductory materials texts. Students are not expected to study all of these

books exhaustively, but rather to master the topics, which may require reading several of them.

2. Students who have taken a course in Solid State Physics may find most of the subjects covered at a higher level in Kittel or in Ashcroft and Mermin. However, since these texts do not cover all of the topics in this exam, such students are encouraged to refer to the representative tests for completeness.
3. The two texts by Callister are very similar but are aimed at slightly different audiences. Their major differences are mainly organizational.
4. In some cases, many of the subtopics are addressed in a single chapter and, therefore, specific sections are not specified. The chapter number is given in the major headings (such as "1") and the subheadings (such as 1.1...) are labeled "--."
5. In the case that a text does not address a topic, the cell is labeled "N.A."

Representative Texts

Call: *Fundamentals of Materials Science and Engineering*, 2nd Ed., William. D. Callister, Jr., John Wiley and Sons, Inc., 2005, ISBN 0-471-47014-7.

Call2: *Materials Science and Engineering - An Introduction*, 6th Ed., William D. Callister, Jr., John Wiley and Sons, Inc., 2003, ISBN 0-471-13576-3.

Sh: *Introduction to Materials Science for Engineers*, 5th Ed., James F. Shackelford, Prentice-Hall, 2000, ISBN 0-13-011287-9.

Ask: *The Science and Engineering of Materials*, 4th Edition, Donald R Askeland and Pradeep P. Phule, Thomson Learning-Brooks/Cole, 2003, ISBN 0-534-95373-5.

Examination Topics

Topic	Reference Text			
	<i>Call</i>	<i>Call2</i>	<i>Sh</i>	<i>Ask</i>
1. Chemical Bonding	2	2	2	2
1.1. Atomic and molecular orbitals	---	---	---	---
1.2. Primary bonding	---	---	---	---
1.3. Secondary bonding	---	---	---	---
2. Basic lattice types	3	3	3	3
2.1. Bravais lattices	---	---	---	---
2.2. Miller indices	---	---	---	---
2.3. Coordination in metals	---	---	---	---
2.4. Interstitial size and location	N.A.	N.A.	N.A.	---
2.5. Relation between coordination number and cation/anion ratio in ceramics	---	12.2	---	---
3. Classes of materials - bond type and general structure	2	2	1.3, 2	1-2, 2
3.1. Metals	---	---	---	---
3.2. Ceramics and inorganic glasses	---	---	---	---
3.3. Semiconductors	---	---	---	---
3.4. Polymers	---	---	---	---
3.5. Composites	15.1	16.2	14 (Intro)	16 (Intro)

Topic	Reference Text			
	Call	Call2	Sh	Ask
4. Mechanical properties				
4.1. Crystal defects	5.1-5.10	4.1-4.8	4	4
4.2. Deformation and fracture (tensile stress-strain)	7.1-7.8	6.1-6.8	6.1-6.3	6-1 thru 6-4
4.3. Strengthening mechanisms	8	7	10	
4.3.1. Solid solution	---	---	---	9-4
4.3.2. Work hardening	---	---	---	7-1 thru 7-3
4.3.3. Grain refining	---	---	---	4-8
4.3.4. Precipitation hardening	11.10-11.12	11.9	---	11-1 thru 11-7
4.3.5. Dispersion hardening	15.3	16.3	---	10-1
5. Electrical properties	12	18	15	12
5.1. Classical theory of electrical conduction	---	---	---	---
5.2. Free and nearly free electron model of metals	---	---	---	---
5.3. Ionic conduction	---	---	---	---
5.4. Conduction in semiconductors	---	---	---	---
6. Thermal properties	17 ¹	19 ²	7.1, 7.3	21-1, 21-3
6.1. Lattice vibrations and phonons	---	---	---	---
6.2. Heat conduction	---	---	---	---
6.3. Heat capacity and the Debye model	---	---	---	---
6.4. Electronic conduction and Wiedemann-Franz ratio	---	---	---	---
6.5. Electronic heat capacity	---	---	---	---
7. Optical Properties	19.1-19.9	21.1-21.9	161-16.2	20-1 thru 20-3
7.1. Bandgap and photonic absorption	---	---	---	---
7.2. Infrared absorption in ionic materials	---	---	---	---
7.3. Polarization and dielectric function	---	---	---	---
7.4. Absorption and transmission	---	---	---	---
8. Magnetic properties	18.1-18.6	20.1-20.6	18.1-18.3	19-1 thru 19-4
8.1. Diamagnetism	---	---	---	---
8.2. Paramagnetism	---	---	---	---
8.3. Ferromagnetism	---	---	---	---
8.4. Ferrimagnetism	---	---	---	---
9. Ferroelectrics			15.4	18-10
9.1. Pyroelectrics	12.24	18.24	N.A.?	---
9.2. Piezoelectrics	12.25	18.25	15.4	---
10. Superconductors	18.12	20.11	15.3	18-4
10.1. Meissner effect	---	---	---	---
10.2. London equations	---	---	---	---
10.3. Type I and II superconductors	---	---	---	---
10.4. High T _c superconductors	---	---	---	---

Section 2 Characterization and Testing

¹ Exclude sections 17.3 and 17.5.

² Exclude sections 19.3 and 19.5.

Exam questions will be taken from:

1. Either Fundamentals of Materials Science and Engineering, 2nd Ed., W.D. Callister (*Call*) or Introduction to Materials Science for Engineers, 5th Ed., J.F. Shackelford (*Sh*).

Note: Similar information may be found in later editions of Callister, but may be in different chapters than those referenced.

2. Either Instrumental Method of Analysis, 5nd Ed., D.A. Skoog, F.J. Holler, T.A. Nieman (*SHN*) or Instrumental Method of Analysis, 7th Ed., H.W. Willard, L.L. Merritt, J.A. Dean (*WMD*)

Crystallography

X-ray Diffraction

Sh 3.7

SHN 12A

Call 3.20

WMD 13, 13.1, 13.2 (*Bragg equation*),

Mechanical properties testing

Tensile testing including modulus of rupture

Sh 6.1

Call 7.2, 7.3, 7.6, 7.7

Impact testing and fracture toughness

Sh 8.1, 8.2, 3.3 (*through spinel structure*), 3.5, 3.6

Call (9.2-)9.8

Fatigue testing

Sh 8.3

Call 9.9, 9.10

Creep testing

Sh 6.5

Call 9.16, 9.17

Hardness tests

Sh 6.4

Call 7.16

Spectroscopy (underlying principles, information obtainable, limitations)

SHN Ch 6A, 6B and 7A-7E

WMD 5-5.6

UV-Vis

At 18.1, 18.2, 18.4

SHN 8A and 13A-13B

WMD 7-7.1

IR-FTIR-Raman

At 17.1 –17.3 (*exclude selection rules*)

SHN 16A-16C and 18A-18B

WMD 11-11.2, 12, 12.1

Optical emission

AA

SHN 9A-9B

WMD 9.4

AES (Atomic Emission Spectroscopy)

SHN 10A-10C

WMD 9.1, 9.2

XRF

SHN 12A, 12C

WMD 5.10, 13, 13.5

XPS/ESCA/EDS/EELS/AES(Auger Emission Spectroscopy)

SHN 21A-21D

WMD 5.9, 13, 13.1, 13.2, 13.7, 13.8

SIMS

SHN 21B

WMD 16.14

NMR (ESR)

At 19.1, 19.2

SHN 19

WMD 5.8, 15- 15.4

Surface Analysis (underlying principles, information obtainable, limitations)

SHN 21A-D for topics covered below

Optical Microscopy

SEM

SPM

LEED

Thermal Analysis (underlying principles, information obtainable, limitations)

TGA, DSC, TG

SHN 31A-31C

WMD 25-25.5

Electrical Characterization

Conductivity measurements

Hall measurements

Call 12.14

Molecular weight determination ? (underlying principles, what is being measured, limitations, etc.)

Gel permeation chromatography/Size exclusion chromatography

WMD 20.9

Light scattering

WMD 7.11 (light scattering only)

Section 3: Thermodynamics and Processing

Text Book

N. A. Gokcen and R. G. Reddy: Thermodynamics, Plenum Press, N.Y., 1996 (GR)

Other References:

R. E. Reed-Hill and Reza Abbaschian: Physical Metallurgy Principles, PWS-Kent Publ. Co., Boston, 1992 (RA)

Y. M. Chiang, D. P. Birnie III and W.D. Kingery: Physical Ceramics, John Wiley & Sons, Inc., New York, 1997 (CBK).

M. Ohring: Materials Science of Thin Films- Deposition and Structure, Academic Press, New York, 2002 (MO)

Syllabus:	<u>Chapter (pages)</u>	<u>Reference text</u>
Thermodynamics		
Fundamentals (GR)		
First Law	3 (37-40)	GR
Enthalpy and Heat Capacity	3 (53-60)	GR
Thermochemistry	3 (60-67)	GR
Second Law	4 (71-78, 87)	GR
Concept of entropy	4 (79-82)	GR
Entropy Change	5 (89-93)	GR
Helmholtz and Gibbs Energies	6 (101-108)	GR
Third Law	7 (109-113, 116-117)	GR
Entropy of Supercooled liquids	7 (114-115)	GR
Gibbs Energy Change of Reactions	12(203-215)	GR
Equilibrium constants	12(204, 212-214, 240-244)	GR
Thermodynamic Equations	12(215-216)	GR
Thermodynamics Tables and Compilations	12(216-238)	GR
Phase Equilibria (GR)		
Single component systems	8 (119-120)	GR
Binary and higher order systems	8 (120-124)	GR
Phase rule	8 (133-135)	GR
Clapeyron equation	8 (119-124)	GR
Fugacity and Activity	9 (139-144)	GR
Raoult's Law	9 (144-145)	GR
Henry's Law	9 (145-149)	GR

Solutions (GR)

Ideal Solutions	10 (151-161)	GR
Real Solutions	10 (162-172)	GR
Dilute Solutions	10 (172-173)	GR
Regular Solutions	11 (189-190)	GR
Partial and Excess Gibbs Energy	8 (130-133, 135-136)	GR
	10(173-175)	GR
	11(179-183)	GR
Equilibria in Gas Mixtures	12(209-212)	GR
Complex Equilibria	12(238-244)	GR
Solutions of Electrolytes (GR)		
Electrolytes	13(247-256, 262-263)	GR
Temkin Rule	13(264)	GR
Half-cell potentials	14(267-272)	GR
Standard emf of Half-cells	14(272-277)	GR
Cells with Solid Electrolytes	14(280-282)	GR
Corrosion –Pourbaix diagrams	App. V (181-183)	GR
Phase Diagrams (GR)		
Binary and ternary phase diagrams	15(285-290, 302-309)	GR
Lever Rule	15(290-291)	GR
Gibbs Energy-composition diagrams	15(291-298)	GR
Order-disorder phenomena	16(330-333)	GR
Surface Tension	16(323-325)	GR
Gibbs Adsorption	16(325-326)	GR
Gravitational Field	16(327-329)	GR
Electric and Magnetic Fields	16(329-330)	GR
Materials processing fundamentals (Basic processes - applications)		
Solidification and Microstructure (RA, CBK)		
Diffusion	12 (360-364)	RA
Fick's laws	12 (362, 373-401)	RA
Nucleation and Growth	14 , 15	RA
Heterogeneous nucleation	15 (495-498)	RA
Growth Kinetics	15 (498-509)	RA
Dendritic growth	14 (444-458)	RA
Segregation	14 (459-467)	RA
Porosity	14 (467- 476)	RA
Martensitic transformations	17 (561-584)	RA
Powder Processing (CBK)		

Solid phase sintering	5 (392-428)	CBK
Hot isostatic pressing	5 (429-430)	CBK
Glass and Glass – Ceramics	5 (430-460)	CBK
Crystallization and Glass Formation	5 (431-446)	CBK

Deposition Processes (MO)

Physical vapor deposition	3	MO
Physics and Chemistry of Evaporation	3 (81-101)	MO
Glow Discharges and Plasmas	3 (101- 109)	MO
Sputtering and Sputtering Processes	3 (109-132)	MO
Hybrid and Modified PVD Processes	3 (132-140)	MO

Chemical vapor deposition	4	
Thermodynamics of CVD	4 (155-176)	MO
CVD processes and systems	4 (177-190)	MO
Low –Pressure CVD (LPCVD)	4 (179-181)	MO
Plasma-Enhanced CVD (PECVD)	4 (181-184)	MO
Laser-Enhanced CVD (LECVD)	4 (185-186)	MO
Metal organic CVD (MOCVD)	4 (186-188)	MO
