Name:__________________________
Student Number: ______________________

E.S. 1021b PROPERTIES OF MATERIALS
FINAL EXAMINATION

APRIL 20, 2010

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University of Western Ontario
Faculty of Engineering

SOLUTIONS

INSTRUCTIONS:

HAND IN THIS BOOKLET, WITH YOUR NAME PRINTED AT THE TOP, AT THE END OF THE EXAMINATION.

- 1 page of handwritten notes (8 1/2 x 11", both sides) is allowed.
- A calculator is allowed.
- No communication with others is allowed at any time.
- Wearing earphones is not allowed.

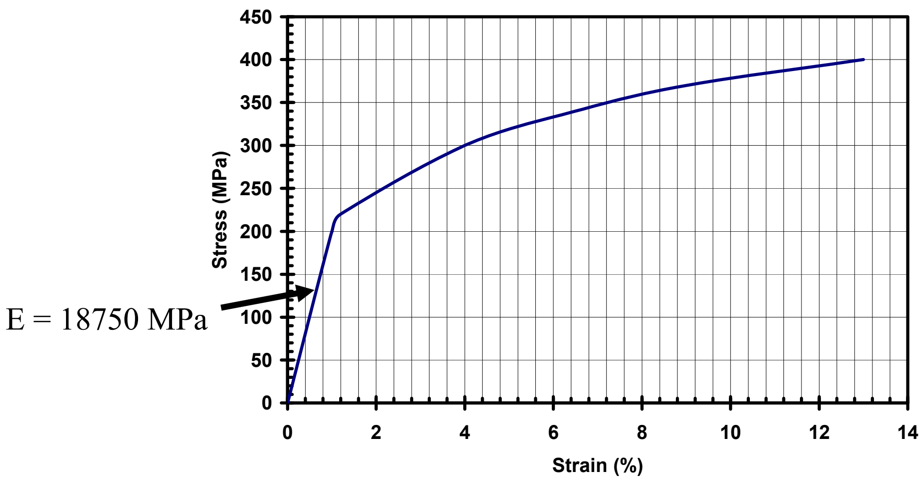
This exam contains 16 pages and has 42 questions. Check to see all pages are here.

TIME ALLOWED: 3 HOURS

Computer Answer Sheet: Use pencil to fill in the squares carefully. Hand in the answer sheet at the end of the test.

1. Print your name and student number.
2. Fill in the student number squares.
3. Fill in the SECTION with 001.
4. **Fill in the CODE with the number 111.**
5. Answer all 42 questions. Each question is worth 1 mark.
6. Fill in the corresponding answers on the computer answer sheet.

CHEATING: **University policy states that cheating is a scholastic offense. The commission of a scholastic offence is attended by academic penalties which might include expulsion from the program. If you are caught cheating, there will be no second warning.**



The engineering stress versus engineering strain curve of a hypothetical metal is shown above. Use this figure to answer Questions 1 to 4.

1 The work required to load this material to a stress of 150 MPa is closest to:

(a) 0.060 kJ/m^3
(b) 600 kJ/m^3
(c) 60000 kJ/m^3
(d) 120000 kJ/m^3
(e) Can't be calculated without knowing the volume of the sample.

2 The elastic strain in the material when it is loaded to a stress of 300 MPa is closest to:

(a) 1.6%
(b) 2.4%
(c) 3.8%
(d) 4.0%
(e) Can not be calculated without knowing the initial length of the sample.

3 If the Poisson's ratio of this material is $\nu = 0.3$, the lateral strain (i.e. the strain in the direction perpendicular to the loading direction) when $\sigma_{applied}$ = 150 MPa is closest to: ("-" indicates a compressive strain)

(a) -0.12%
(b) -0.24%
(c) -0.40%
(d) -0.80%
(e) +0.40%

4 If a sample of this metal is loaded to a *total* strain of 7.2%, the plastic strain endured by the sample is closest to:

(a) 1.87 %
(b) 5.33 %
(c) 6.12 %
(d) 6.97 %
(e) 7.20 %

5 The crystal structure that results from stacking close-packed planes of atoms in an ABCABCABC….. sequence is:

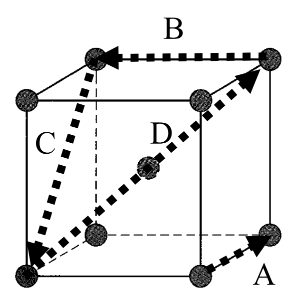
(a) an FCC crystal structure.
(b) a CPH (HCP) crystal structure.
(c) a BCC crystal structure.
(d) (a) or (b) is correct.
(e) None of the above.

6 If the dimension, a, of the side of an FCC unit cell is 1.0 nm, the atomic radius is closest to:

(a) 0.35 nm
(b) 0.43 nm
(c) 0.50 nm
(d) 0.58 nm
(e) 0.71 nm

7 The sketch below shows a body centered cubic unit cell (the atoms are shown reduced in size for clarity). The atomically close packed direction (s) are given by the arrow(s) labeled:

(a) A
(b) B
(c) C
(d) A and B
(e) D

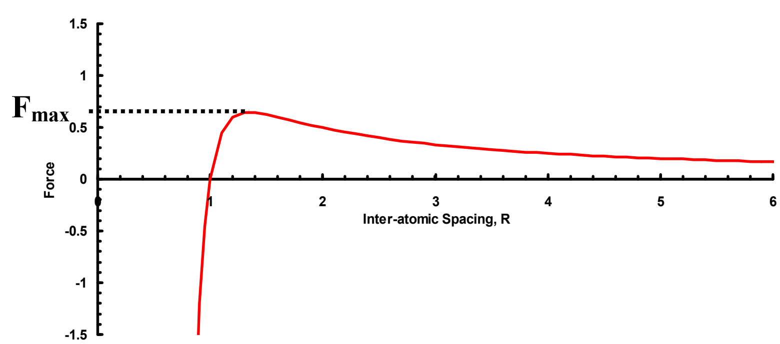


8 The metal molybdenum has a body centered cubic crystal structure. If the atomic weight of molybdenum is 95.94 grams/mole and the atomic radius is 0.139×10^{-9} m, the density of molybdenum is closest to:

(a) 6637 kg/m^3
(b) 8894 kg/m^3
(c) 9632 kg/m^3
(d) 12356 kg/m^3
(e) 18395 kg/m^3

9 Table salt, NaCl, has a rock salt crystal structure. The volume of the NaCl unit cell is 0.1813 nm^3. The radius of a Na^+ ion is 0.102 nm while the radius of a Cl^- ion is 0.181 nm. The density of NaCl is closest to:
(The atomic weight of Na is 22.99 g/mole and Cl is 35.45 g/mole.
1 nm = 10^{-9}m.)

(a) 808 kg/m^3
(b) 977 kg/m^3
(c) 1032 kg/m^3
(d) 1864 kg/m^3
(e) 2140 kg/m^3



10 The figure above depicts a typical plot of inter-atomic force F versus inter-atomic spacing R for a crystalline solid. The Young's modulus E of this material is related to which of the following parameters?

(a) The slope of the F vs. R curve at R = 0.
(b) The slope of the F vs. R curve at F = 0.
(c) The area under the F vs. R curve.
(d) The value of F_{max}.
(e) The value of F at R = ∞.

Material	Density, ρ (kg/m^3)	Young's Modulus, E (GPa)	Material Cost ($/kg)		
A	5000	300	1.0		
B	4000	200	0.5		
C	3800	200	0.8		
D	3500	180	0.6		
E	3000	170	1.2		

You wish to design a tie-rod that will not deflect more than a fixed amount when loaded in uniaxial tension to a predetermined force. The tie-rod is of a fixed length ℓ but the cross-sectional area A_0 can be changed.

The following equations relate the applied force, F, to the deflection, $\Delta\ell$, of the tie-rod:

$$\sigma = E\varepsilon$$

$$\Delta\ell = \frac{F\ell}{EA_0}$$

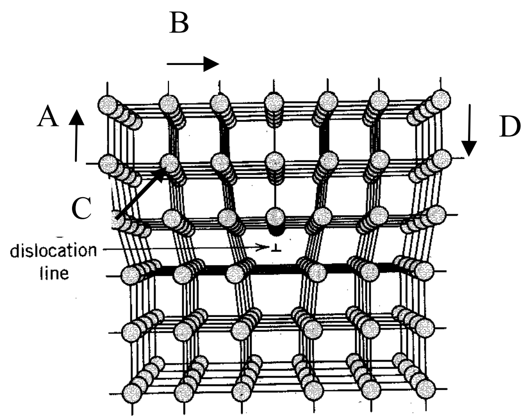
Use this information to answer Questions 11 and 12.

11 The best material choice from Table 1 for the lightest possible tie-rod is:

(a) Material A
(b) Material B
(c) Material C
(d) Material D
(e) Material E

12 The best material choice from Table 1 for the least expensive tie-rod is:

(a) Material A
(b) Material B
(c) Material C
(d) Material D
(e) Material E

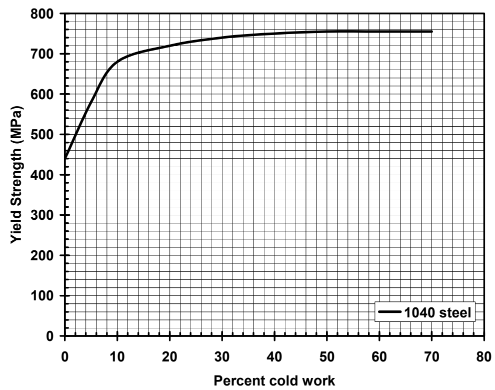


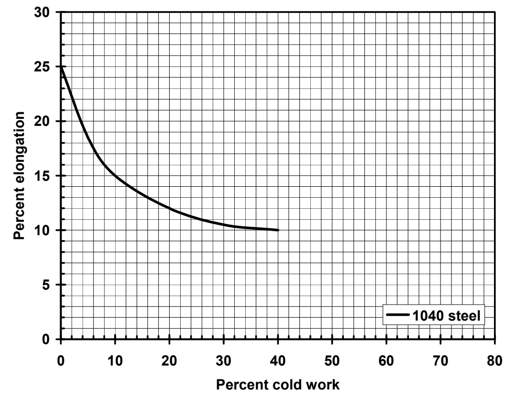
13 The crystal shown in the figure above contains a dislocation (dislocation line is labeled). If the positive direction of the dislocation line points into the page, which of the arrows shown in the figure corresponds to the Burgers vector of the dislocation?

a) Arrow A
b) Arrow B
c) Arrow C
d) Arrow D
e) None of the arrows, the Burgers vector runs parallel to the dislocation line.

14 A certain metal has a yield strength of 200 MPa when it has an average grain diameter of 10 μm. The yield strength of the same material is 100 MPa when the average grain diameter is increased to 20 μm. The yield stress of this material when the grain size is increased to 30 μm is closest to:

(a) 55 MPa
(b) 66 MPa
(c) 78 MPa
(d) 86 MPa
(e) 96 MPa





15 A plate of 1040 steel is 15 mm thick and must be reduced to a final thickness of 7 mm by a cold-rolling / anneal / cold-rolling process. The finished product must have a yield strength of at least 700 MPa and an elongation of at least 13%. Using the data in the graphs shown above, the amount that the piece of steel is rolled in the first cold-rolling step, prior to annealing, is closest to:

a) 15%
b) 25%
c) 35%
d) 45%
e) 55%

16 Which of the following is not a strengthening method for crystalline metals?

(a) Hot-working.
(b) Cold-working.
(c) Grain refinement.
(d) Interstitial alloy addition.
(e) None of the above. These are all strengthening methods.

17 Steel is:

(a) An alloy of iron and carbon.
(b) A traditional alloy that was developed by adding nickel to bronze alloys.
(c) Another name for pure iron.
(d) Any material that can be made to be permanently magnetic.
(e) All of the above.

18 Tempering can make window glass much more resistant to fracture because:

(a) The tempering process causes the glass to transform into a crystalline ceramic.
(b) The rapid cooling associated with the tempering process introduces compressive stress to the surface of the glass thereby forcing surface cracks to be closed.
(c) The tempering process causes the glass to be raised above its glass transition temperature. It therefore becomes more ductile.
(d) The tempering process promotes the creation of precipitates within the glass which make dislocation motion more difficult.
(e) The tempering process causes the window glass to recrystallize and thereby become more resistant to fracture.

19 The microstructure of a "Traditional" clay product consists of

(a) 100% non-crystalline "glass" structure.
(b) 100% crystalline structure.
(c) A crystalline ceramic matrix surrounding non-crystalline "glass" particles.
(d) A non-crystalline "glass" matrix surrounding crystalline ceramic particles.
(e) A crystalline ceramic matrix surrounding steel reinforcing bars.

20 The difference between quartz and window glass (soda-lime glass) is:

(a) Quartz contains SiO_2 while window glass does not.
(b) Quartz has short-range atomic order while window glass does not.
(c) Quartz is crystalline SiO_2 while window glass is non-crystalline SiO_2.
(d) Quartz has a lower melting temperature than window glass.
(e) Both (b) and (c) are correct.

21 The glass transition temperature is the temperature where, upon heating, the material:

(a) transforms from crystalline to non-crystalline structure.
(b) transforms from non-crystalline to crystalline structure.
(c) melts.
(d) experiences a sharp increase in electrical conductivity.
(e) experiences a sharp decrease in stiffness and becomes like a very viscous liquid.

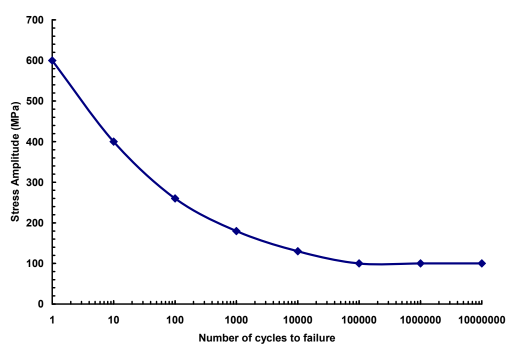
22 A tungsten carbide sample has an ultimate tensile strength of 2800 MPa and a K_{IC} of 20 $MPa.m^{1/2}$ *. If the sample has a square cross section, of 5 mm x 5mm, the total length of the surface crack that must be present for the sample to break at a load of 12.6 kN is closest to:

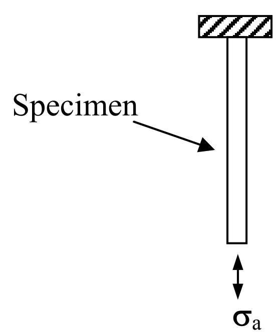
a) 0.05 mm
b) 0.10 mm
c) 0.5 mm
d) 1.0 mm
e) 2.5 mm

*** Assume Y = 1.**

23 A certain brittle ceramic material containing a sharp surface crack of length c = 125 μm is loaded in uniaxial tension to a stress of σ = 300 MPa. The local stress at a radial distance of 35 μm from the crack tip is closest to (1 μm = 1×10^{-6} m, assume Y = 1):

a) 300 MPa.
b) 412 MPa.
c) 701 MPa.
d) 867 MPa.
e) 1011 MPa.





24 A sinusoidal alternating stress $\pm \sigma_a$ is applied to the cylindrical specimen (diameter d_0 = 2.0 cm and length l_0 = 10.0 cm) shown above. The S-N curve for the material is also shown above. The maximum alternating load that can be applied to this specimen without having to worry about it ever failing by fatigue is closest to:

a) ± 1.26 kN
b) ± 31.4 kN
c) ± 98.0 kN
d) ± 3142 kN
e) ± 4000 kN

25 One mole of a hypothetical crystalline metal contains $5.5x10^{20}$ vacancies at 600^oC (873K). The activation energy Q_v for vacancy formation is closest to:

($k = 1.381x10^{-23}$ Joules/K, R = 8.316 Joules/(mole.K), $N_{Avogadro} = 6.023x10^{23}$):

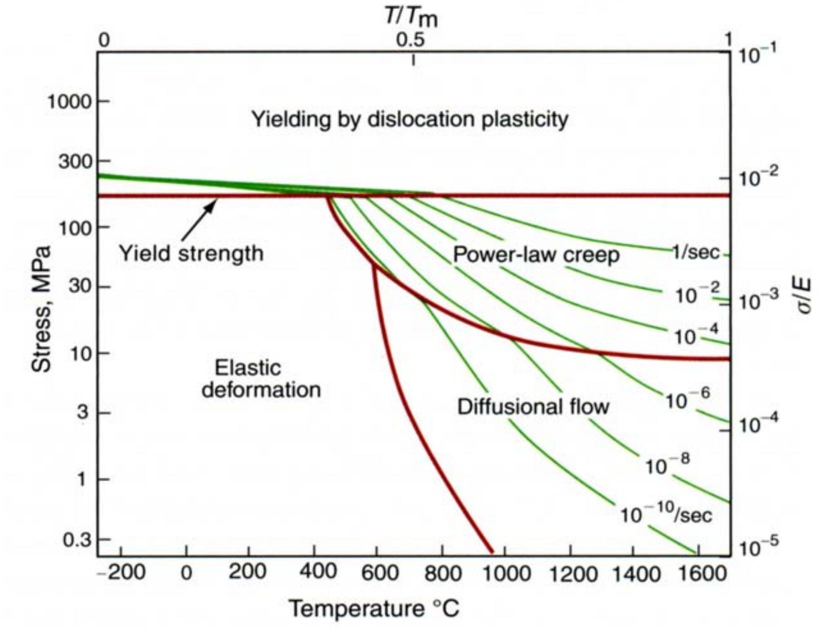
a) $8.44x10^{-20}$ Joules/mole
b) $9.13x10^{-4}$ Joules/mole
c) 22066 Joules/mole
d) 34920 Joules/mole
e) 50809 Joules/mole

26 A hypothetical crystalline metal has an activation energy for vacancy formation of $q_v = 5.56\ x10^{-21}$ Joules and an activation energy for atom migration of $q_m = 6.13\ x\ 10^{-21}$ Joules. The activation energy for diffusion Q_d of this metal is closest to:

a) $5.56\ x10^{-21}$ Joules/mole
b) $6.13\ x\ 10^{-21}$ Joules/mole
c) $1.17x10^{-20}$ Joules/mole
d) 3692 Joules/mole
e) 7041 Joules/mole

27 A certain alloy undergoes *power-law* creep deformation. When the alloy is subjected to a stress of $\sigma = 50$ MPa it creeps at a steady-state creep rate of $\dot{\varepsilon}_{ss} = 1.0x10^{-7}\ \text{sec}^{-1}$. The $\dot{\varepsilon}_{ss}$ of this alloy when the applied stress is increased to $\sigma = 70$ MPa (the temperature remains the same) is closest to:

a) $1.0x10^{-7}\ sec^{-1}$
b) $1.4x10^{-7}\ sec^{-1}$
c) $6.8x10^{-7}\ sec^{-1}$
d) $7.6x10^{-7}\ sec^{-1}$
e) Can't be calculated without knowing the power-law stress exponent.



Use the deformation mechanism map shown above to answer Questions 28 and 29.

28 The maximum temperature that this material could be exposed to if it was not allowed to deform more than 1% over 10,000 hours while subjected to a constant stress of 100 MPa is closest to:

Answer (b) was also marked as correct in this problem.

a) 200 ^{o}C.
b) 400 ^{o}C.
c) 700 ^{o}C.
d) 800 ^{o}C.
e) 1000 ^{o}C.

29 The maximum temperature that this material could be exposed to without it ever deforming significantly by creep at any stress less than the yield strength is closest to:

a) 200 ^{o}C.
b) 400 ^{o}C.
c) 700 ^{o}C.
d) 800 ^{o}C.
e) 1000 ^{o}C.

30 Copper has an electrical conductivity is 8.0×10^{7} $Ohm^{-1}m^{-1}$. The mobility of a conducting electron in Cu is 0.0040 m^2/V-s while the mobility of holes is 0.0010 m^2/V-s. The electrical resistance of a Cu wire (diameter = 4mm, length = 500m) is closest to:

a) 0.180 Ohms.
b) 0.321 Ohms.
c) 0.433 Ohms.
d) 0.500 Ohms.
e) 0.790 Ohms.

(The charge on one electron is 1.6×10^{-19} Coulombs.)

31 A hypothetical metal has an electrical conductivity of 2.0×10^{7} $Ohm^{-1}m^{-1}$ and an electron mobility of 0.0040 m^2/V-s. The voltage that must be applied across a 2 meter length of this material to get the conducting electrons to move at a average drift velocity of 0.001 m/sec is closest to:

a) 0.5 Volts.
b) 12.0 Volts.
c) 19.3 Volts.
d) 112 Volts.
e) Can not be calculated with the information given.

(The charge on one electron is 1.6×10^{-19} Coulombs.)

32 A hypothetical intrinsic semiconductor has $n_{electrons} = 3 \times 10^{20}/m^3$ conducting electron charge carriers. The mobility of the electron charge carriers is $\mu_{electron}=0.19\ m^2.V^{-1}.S^{-1}$ and the mobility of the electron holes is $\mu_{holes} = 0.05\ m^2V^{-1}S^{-1}$. The number of electron hole charge carriers n_{holes} is closest to:

a) $1.5 \times 10^{19}/m^3$
b) $7.9 \times 10^{19}/m^3$
c) $3.0 \times 10^{20}/m^3$
d) $4.3 \times 10^{20}/m^3$
e) Can not be calculated without knowing the electrical conductivity of this material.

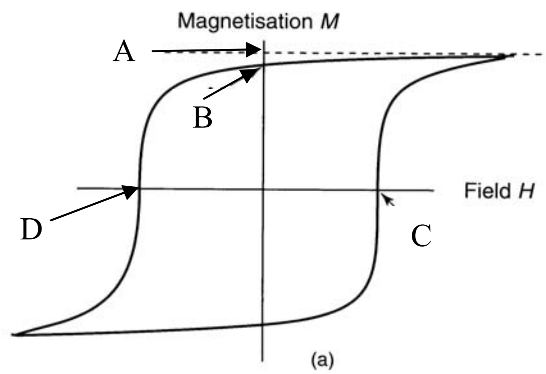
33 Atoms of a Group V element are deposited into silicon to create an n-type extrinsic semiconductor with $n_{electrons} = 1x10^{18}$ /m^3. If the mobility of the conducting electrons = 0.19 m^2.V^{-1}.S^{-1} the conductivity of this n-type intrinsic semiconductor when it is operating in the donor exhaustion range is closest to:

a) 10^{-10} Ω^{-1} m^{-1}
b) 0.030 Ω^{-1} m^{-1}
c) 0.008 Ω^{-1} m^{-1}
d) 0.038 Ω^{-1} m^{-1}
e) 0.080 Ω^{-1} m^{-1}

(The charge on one electron is 1.6x10^{-19} Coulombs.)

34 A p-n junction rectifier will conduct electricity when:

a) No voltage is applied to the device.
b) A reverse bias voltage is applied to the device.
c) A forward bias voltage is applied to the device.
d) The temperature of the device is changed rapidly.
e) A p-n junction device never conducts electricity (it's an insulator).



35 The remnant magnetization M_r corresponds to which of the points indicated on the M vs. H magnetic hysteresis plot shown above?

a) Point A
b) Point B
c) Point C
d) Point D
e) The area subtended within the M-H hysteresis plot.

36 The coercive magnetic field strength H_c corresponds to which of the points indicated on the M vs. H magnetic hysteresis plot shown above?

a) Point A
b) Point B
c) Points C and D
d) The tangent of the M vs H curve.
e) The area subtended within the M-H hysteresis plot.

37 A ferromagnetic material is defined as:

a) A material that can be made to be permanently magnetic.
b) A magnetic alloy that contains iron.
c) A ceramic that has a very low M-H energy products.
d) A piezoelectric material that can be used as a force actuator.
e) A dielectric material with a very high capacitance.

38 A capacitor consists of plates of $6.45x10^{-4}$ m^2 area separated by a 2 mm thick dielectric material of $\varepsilon_r = 6.0$. The capacitance C of this device is closest to:
$(\varepsilon_0 = 8.854x10^{-12} F/m)$

a) $5.31x10^{-15}$ Farads
b) $1.71x10^{-14}$ Farads
c) $1.71x10^{-11}$ Farads
d) $1.935x10^{-3}$ Farads
e) 1.935 Farads

39 A parallel plate capacitor, each plate has an area of $7.85x10^{-5}$ m^2, has a capacitance of $2.0\ x10^{-10}$ Farads. The dielectric displacement Q of this capacitor when a 150 Volt potential is applied is closest to:

a) $1.16x10^{-8}$ Coulombs/m^2
b) $7.43x10^{-6}$ Coulombs/m^2
c) $2.55x10^{-5}$ Coulombs/m^2
d) $1.89x10^{-4}$ Coulombs/m^2
e) $3.82x10^{-4}$ Coulombs/m^2

40 The maximum energy that can be stored in a capacitor that has a capacitance of $9.0x10^{-11}$ Farads and a breakdown voltage of $V_{breakdown}$ = 10000 V is closest to:
(1 Volt = 1 Joule/Coulomb)

a) 0.0045 Joules
b) 0.0782 Joules
c) 1.2840 Joules
d) 12.840 Joules
e) Can not calculate the energy without knowing the thickness, the area, and the dielectric constant of the capacitor.

41

Material	Density, ρ (kg/m^3)	Dielectric constant, ε_r (ε_0 = 8.854x10^{-12} F/m)	Breakdown field strength. $E_{breakdown}$ (V/m)	
A	1000	6.0	1x10^6	
B	2000	7.0	3x10^6	
C	4000	9.0	8x10^8	
D	16000	5.5	4x10^7	
E	35000	15.0	7x10^8	

The table above lists the dielectric properties of five hypothetical materials. The lightest possible material listed in the table that could be used for a capacitor that must be able to store a fixed amount of energy is (the surface area A of the capacitor is fixed but the thickness t is adjustable):

a) Material A.
b) Material B.
c) Material C.
d) Material D.
e) Material E.

42 A certain piezoelectric material has a ferro-electric coefficient of k = 2.8x10^{-6} m/V and an elastic modulus of 70 GPa. If a sample of this material is 3 mm thick, the compressive stress that must be applied to cause the material to produce a 15 V output (see figure below) is closest to:

a) 200 MPa.
b) 980 MPa.
c) 1931 MPa.
d) 34350 MPa.
e) 62000 MPa.