AP physics C
2009 Elec./MAG M.C.

TABLE OF INFORMATION FOR 2008 and 2009

CONSTANTS AND CONVERSION FACTORS

Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude,	$e = 1.60 \times 10^{-19}$ C
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg	1 electron volt,	1 eV $= 1.60 \times 10^{-19}$ J
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg	Speed of light,	$c = 3.00 \times 10^{8}$ m/s
Avogadro's number,	$N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant,	$G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Universal gas constant,	$R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface,	$g = 9.8$ m/s^2
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K		

1 unified atomic mass unit,	1 u $= 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N·m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}$ N·m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}$ (T·m)/A
1 atmosphere pressure,	1 atm $= 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

UNIT SYMBOLS								
	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron-volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

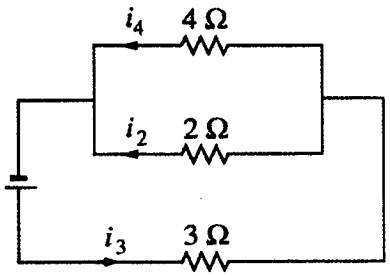
III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

PHYSICS C: ELECTRICITY AND MAGNETISM
SECTION I
Time—45 minutes
35 Questions

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding oval on the answer sheet.

1. A positive point charge is initially at rest close to a bar magnet that is also at rest. The charge will

   (A) be attracted to the north pole of the magnet
   (B) be repelled by the north pole of the magnet
   (C) be attracted to the south pole of the magnet
   (D) be repelled by the south pole of the magnet
   (E) experience no magnetic force



2. Resistors of resistance 4 Ω, 2 Ω, and 3 Ω are connected in a circuit, as shown above. The currents through the resistors are i_4, i_2, and i_3, respectively. Which of these currents is least and which is greatest?

	Least	Greatest
(A)	i_4	i_3
(B)	i_2	i_4
(C)	i_2	i_3
(D)	i_3	i_4
(E)	i_3	i_2

3. Which of the following is a possible unit for electric field?

   (A) Volt·meter
   (B) Joule·coulomb
   (C) Joule·newton
   (D) Joule per coulomb
   (E) Newton per coulomb

4. An emf is induced by a changing magnetic flux in the operation of all of the following EXCEPT

   (A) an electric generator
   (B) a transformer
   (C) an eddy current brake
   (D) an inductor
   (E) a mass spectrometer

5. A solid conducting sphere carries a charge $+Q$. Which of the following is true of the electric field E and the electric potential V inside the sphere?

   (A) $E = 0$ and $V = 0$
   (B) $E = 0$ and $V \neq 0$
   (C) $E \neq 0$ and $V = 0$
   (D) $E \neq 0$ and $V \neq 0$
   (E) It cannot be determined without knowing the radius of the sphere.

6. A capacitor with circular parallel plates of radius R that are separated by a distance d has a capacitance of C. What would the capacitance be if the plates had radius $2R$ and were separated by a distance $d/2$?

   (A) $C/2$
   (B) C
   (C) $2C$
   (D) $4C$
   (E) $8C$

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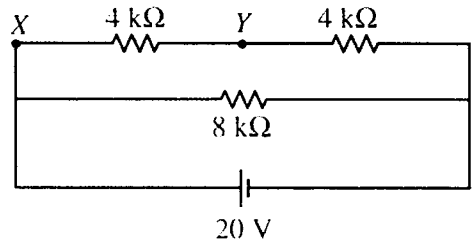
Questions 7-8



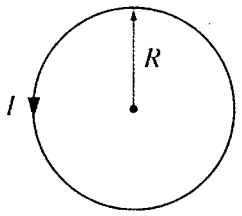
A network of three resistors is connected to a 20 V battery, as shown above.

7. What is the equivalent resistance of the network?

   (A) 4 kΩ
   (B) 8 kΩ
   (C) 10 kΩ
   (D) 12 kΩ
   (E) 16 kΩ

8. What is the potential difference between the points X and Y?

   (A) 0 V
   (B) 5 V
   (C) 10 V
   (D) 15 V
   (E) 20 V



9. The single, circular wire loop of radius R shown above carries a current I that produces a magnetic field B at the center of the loop. If the current remains constant while the loop is enlarged to a radius of $2R$, what happens to the magnetic field at the center?

   (A) It decreases to $B/2$.
   (B) It increases to $2B$.
   (C) It changes to B^2.
   (D) It changes to $\sqrt{B}$.
   (E) It remains unchanged.

10. A capacitor charged to a potential difference V stores an amount of energy U_0. If the potential difference is doubled, what is the new stored energy?

    (A) $U_0/4$
    (B) $U_0/2$
    (C) U_0
    (D) $2U_0$
    (E) $4U_0$

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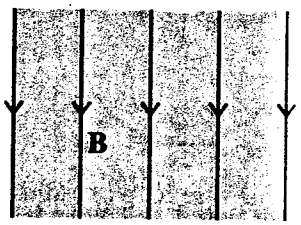
Questions 11-12



A uniform magnetic field **B** directed downward parallel to the plane of the page exists in the shaded region shown above. An electron can enter the field from different directions.

11. Suppose that the electron is moving straight down in the same direction as $\boldsymbol{B}$ when it enters the region of the magnetic field. What is the direction of the magnetic force, if any, on the electron when it first enters the field region?

    (A) Toward the bottom of the page
    (B) Toward the top of the page
    (C) To the left
    (D) To the right
    (E) None; there is no magnetic force on the electron.

12. Suppose that the electron is moving perpendicularly into the plane of the page when it enters the region of the magnetic field. What is the direction of the magnetic force, if any, on the electron when it first enters the field region?

    (A) Toward the bottom of the page
    (B) Toward the top of the page
    (C) To the left
    (D) To the right
    (E) None; there is no magnetic force on the electron.

Questions 13-14

The following are configurations of electric charges located at the vertices of an equilateral triangle. Point P is in the plane of the triangle and equidistant from the charges.

(A) $+q$ ------ $+q$, P, $+q$

(B) $+q$ ------ $+q$, P, $-q$

(C) $-q$ ------ $-q$, P, $+q$

(D) $+q$ ------ $-q$, P, $-2q$

(E) $+3q$ ------ $-q$, P, $-2q$

13. In which configuration is the electric field at P pointed directly toward one of the charges?

14. In which configuration is the electric potential at P equal to zero?

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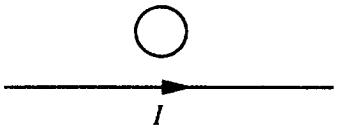
15. The electric potential is 50 V at point X and 70 V at point Y. What is the minimum average power needed by an external force to move a charge of 4 μC from rest at X to rest at Y in 5 s ?

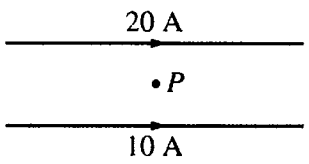
(A) 1.0×10^{-3} W
(B) 9.6×10^{-4} W
(C) 4.0×10^{-4} W
(D) 8.0×10^{-5} W
(E) 1.6×10^{-5} W



16. A small, circular loop of conducting wire is near a long, straight wire that carries a steady electric current I to the right, as shown above. Which of the following actions will result in a clockwise induced electric current in the wire loop?

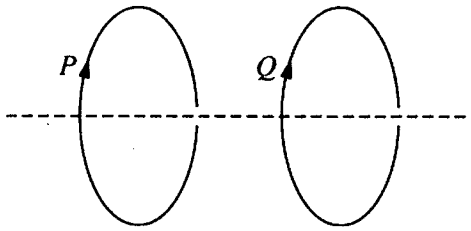
I. The wire loop is pulled vertically upward in the plane of the page (away from the wire) at a constant speed.
II. The current in the straight wire is steadily increasing.
III. The wire loop is rotated about a diameter through a small angle so that it is no longer in the plane of the page.

(A) I only
(B) II only
(C) III only
(D) Either I or II
(E) Either I or III



17. Two long, straight, horizontal wires, parallel to each other in the plane of the page, carry electric currents to the right, as shown in the figure above. What is the direction of the net magnetic field at point P midway between the two wires?

(A) Toward the right
(B) Toward the top of the page
(C) Toward the bottom of the page
(D) Into the plane of the page
(E) Out of the plane of the page



18. Two circular loops of wire, P and Q, are arranged coaxially, as shown above. The current in P is in the direction of the arrowhead. Which of the following is a correct statement?

(A) If P is moving toward Q, a current is induced in Q in the direction of the arrowhead.
(B) If Q is moving toward P, a current is induced in Q in the direction opposite to the arrowhead.
(C) If the current in P is switched off, a current is induced momentarily in Q in the direction opposite to the arrowhead.
(D) If Q carries a current in the direction of the arrowhead, the loops repel one another.
(E) If Q carries a current in the direction opposite to the arrowhead, the loops attract one another.

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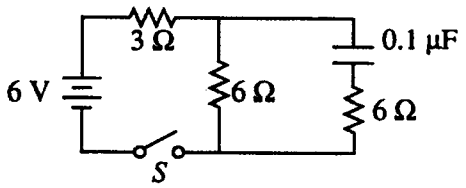
Questions 19-20



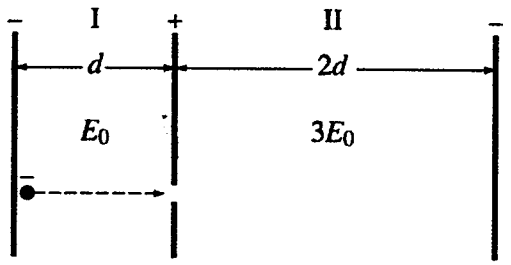
In the circuit shown above, the capacitor is initially uncharged. The switch S is then closed.

19. Immediately after the switch is closed, the current in the 3 Ω resistor is most nearly

(A) 0 A
(B) 0.20 A
(C) 0.50 A
(D) 0.67 A
(E) 1.0 A

20. A long time after the switch is closed, the current in the 3 Ω resistor is most nearly

(A) 0 A
(B) 0.20 A
(C) 0.50 A
(D) 0.67 A
(E) 1.0 A



21. A negatively charged particle initially in region I, as shown above, is accelerated from rest by an electric field of magnitude E_0 between two parallel plates separated by a distance d. The particle then enters region II, the space between two parallel plates with a separation $2d$ and an electric field of magnitude $3E_0$ in the opposite direction. How far into region II does the particle travel before reversing direction?

(A) $\frac{d}{3}$
(B) $\frac{d}{2}$
(C) $\frac{2d}{3}$
(D) d
(E) $\frac{3d}{2}$

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22. A student wants to construct an inductor of a given inductance using copper wire and a plastic tube. If a sufficient supply of copper wire is available, the student will also need a

(A) meterstick only
(B) secondary coil and a meterstick
(C) resistor of known resistance and a meterstick
(D) voltmeter and a meterstick
(E) voltmeter and a DC power supply

23. Correct statements about a constant magnetic field acting on a charged particle include which of the following?

I. The field can accelerate the particle.
II. The field can change the kinetic energy of the particle.
III. The field can do positive work on the particle.

(A) I only
(B) III only
(C) I and II only
(D) II and III only
(E) I, II, and III

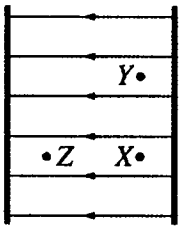
24. A metal wire has a resistance R when it is at a temperature T. The wire is melted and all of the metal is used to reform it into a new wire 4 times as long. What is the resistance of the new wire at temperature T?

(A) R
(B) $2R$
(C) $4R$
(D) $8R$
(E) $16R$

25. An isolated hollow conducting sphere carries a total positive charge Q. Correct statements about the electric field produced by the charged sphere include which of the following?

I. It is directed radially outward from the surface of the sphere.
II. It is equal to zero outside the sphere.
III. It is equal to zero inside the sphere.

(A) I only
(B) II only
(C) III only
(D) I and III
(E) II and III



26. The diagram above shows the electric field lines due to two charged parallel metal plates. X, Y, and Z are locations where charges may be placed. Which of the following is true?

(A) The left plate is positive and the right plate is negative.
(B) A negative charge at X experiences a greater force than if it were placed at Y.
(C) A positive charge at X experiences less force than if it were placed at Y.
(D) A negative charge at X experiences less force than if it were placed at Z.
(E) A positive charge at X would experience the same force if it were placed at Z.

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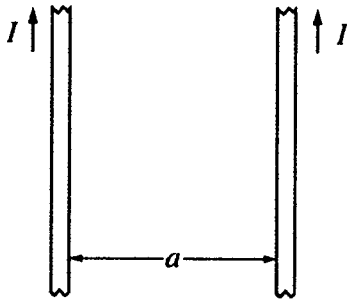
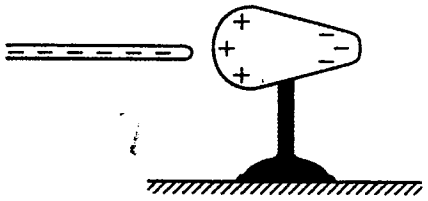
27. When two metal objects, X and Y, are connected to each other by a conducting wire, object X gains electrons. From this information, it can be inferred that before the connection was made, object X, compared with object Y, must have had

(A) less capacitance
(B) more electrical potential energy
(C) a smaller dielectric constant
(D) a greater electric charge
(E) a greater electric potential



28. Two long, straight, current-carrying wires are parallel to each other in the plane of the page and separated by a distance a, as shown above. The direction of the current I in each wire is toward the top of the page. Which of the following best represents the force per unit length acting on the wires?

(A) A repulsive force of magnitude $\mu_0 I^2/2\pi a$
(B) A repulsive force of magnitude $\mu_0 I/2\pi a$
(C) An attractive force of magnitude $\mu_0 I^2/2\pi a$
(D) An attractive force of magnitude $\mu_0 I/2\pi a$
(E) Zero



29. A negatively charged rod is brought near a metal object on an insulating stand, as shown above. When charges stop moving, the left side of the object has an excess of positive charge, and the right side of the object, where the radius of curvature is less, has an excess of negative charge. Which of the following best describes the electric potential on the metal object?

(A) It is greatest on the positively charged side of the object.
(B) It is greatest on the negatively charged side of the object.
(C) It is greatest at the center of the object.
(D) It is the same everywhere on the object.
(E) It cannot be determined from the information given.

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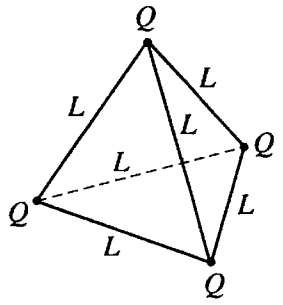
Questions 30-31



Four identical charged particles, each with charge Q, are fixed in place in the shape of an equilateral pyramid with sides of length L, as shown above.

30. What is the electrical potential energy of this arrangement of charges?

(A) $\frac{1}{4\pi\epsilon_0}\frac{Q^2}{L}$

(B) $\frac{2}{4\pi\epsilon_0}\frac{Q^2}{L}$

(C) $\frac{3}{4\pi\epsilon_0}\frac{Q^2}{L}$

(D) $\frac{4}{4\pi\epsilon_0}\frac{Q^2}{L}$

(E) $\frac{6}{4\pi\epsilon_0}\frac{Q^2}{L}$

31. One of the four charged particles is released and allowed to move away under the influence of the electrostatic force from the other three charges. How much kinetic energy will it have when it is very far away?

(A) $\frac{1}{4\pi\epsilon_0}\frac{Q^2}{L}$

(B) $\frac{2}{4\pi\epsilon_0}\frac{Q^2}{L}$

(C) $\frac{3}{4\pi\epsilon_0}\frac{Q^2}{L}$

(D) $\frac{4}{4\pi\epsilon_0}\frac{Q^2}{L}$

(E) $\frac{6}{4\pi\epsilon_0}\frac{Q^2}{L}$

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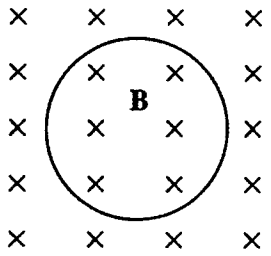


32. The circular wire loop shown above has resistance 30 Ω and area 3.0 m^2, and is fixed in position in the plane of the page. A uniform magnetic field **B** is directed perpendicularly into the plane of the page. The constant rate at which the magnetic field would have to change in order to induce a current of 1.0 mA in this loop is most nearly

(A) 3.0×10^{-4} T/s

(B) 1.0×10^{-3} T/s

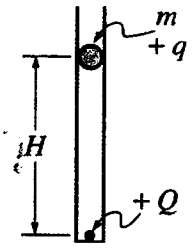
(C) 3.0×10^{-3} T/s

(D) 1.0×10^{-2} T/s

(E) 3.0×10^{-2} T/s

33. Two identical capacitors, X and Y, are connected in series across a battery. A dielectric material with $\kappa = 5$ is placed in capacitor X. Once equilibrium is reached, how do the potential differences across the two capacitors and their charges compare?

	Potential Difference	Charge
(A)	$V_x > V_y$	$Q_x > Q_y$
(B)	$V_x > V_y$	$Q_x = Q_y$
(C)	$V_x = V_y$	$Q_x > Q_y$
(D)	$V_x < V_y$	$Q_x = Q_y$
(E)	$V_x < V_y$	$Q_x < Q_y$



34. A small sphere of mass m and charge $+q$ is constrained to move vertically in an insulating cylinder, as shown above. At the bottom of the cylinder is a point charge $+Q$. At what height H above the bottom of the cylinder will the small sphere of mass m be in equilibrium?

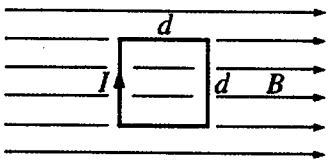
(A) $\frac{kqQ}{mg}$

(B) $\frac{mg}{kqQ}$

(C) $\frac{kqQ}{\sqrt{mg}}$

(D) $\frac{\sqrt{mg}}{kqQ}$

(E) $\sqrt{\frac{kqQ}{mg}}$



35. When a square wire loop of side d carrying current I is in a uniform magnetic field of magnitude B in the position shown above, there is a torque on the loop. The magnitude of this torque is

(A) directly proportional to d
(B) directly proportional to d^2
(C) inversely proportional to d
(D) inversely proportional to d^2
(E) independent of d

STOP

END OF ELECTRICITY AND MAGNETISM SECTION I

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Diagnostic Guide for the 2009 AP Physics C: Electricity and Magnetism Exam

Electrostatics; Conductors, Capacitors (Average number correct = 8.1)

Question #	3	5	6	10	13	14	15	21	25	26	27	29	30	31	33	34
Correct/Incorrect																
Percent of Students Answering Correctly	*68*	*56*	*60*	*56*	*76*	*40*	*50*	*42*	*82*	*55*	*39*	*14*	*36*	*44*	*27*	*63*

Electric Circuits (Average number correct = 3.7)

Question #	2	7	8	19	20	24
Correct/Incorrect						
Percent of Students Answering Correctly	*75*	*89*	*64*	*57*	*54*	*31*

Magnetostatics; Electromagnetism (Average number correct = 6.3)

Question #	1	4	9	11	12	16	17	18	22	23	28	32	35
Correct/Incorrect													
Percent of Students Answering Correctly	*69*	*52*	*59*	*81*	*49*	*46*	*72*	*49*	*16*	*26*	*40*	*36*	*38*

Number Correct

	Electrostatics; Conductors, Capacitors	**Electric Circuits**	**Magnetostatics; Electromagnetism**
Number of Questions	16	6	13
Average Number Correct	8.1 (50.6%)	3.7 (61.7%)	6.3 (48.5%)
My Number Correct			

Chapter VII: Answers to the 2009 AP Physics C: Electricity and Magnetism Exam

- Section I: Multiple Choice
  - Section I Answer Key and Percent Answering Correctly
  - Analyzing Your Students' Performance on the Multiple-Choice Section
  - Diagnostic Guide for the 2009 AP Physics C: Electricity and Magnetism Exam
- Section II: Free Response
  - Comments from the Chief Reader
  - Scoring Guidelines, Sample Student Responses, and Commentary

Section I: Multiple Choice

Listed below are the correct answers to the multiple-choice questions, the percent of AP students who answered each question correctly by AP score, and the total percent answering correctly.

Section I Answer Key and Percent Answering Correctly

Item No.	Correct Answer	Percent Correct by Score					Total Percent Correct
		5	4	3	2	1	
1	E	90	72	64	52	33	69
2	A	89	77	70	66	48	75
3	E	89	72	60	48	32	68
4	E	70	50	44	39	31	52
5	B	77	57	48	40	27	56
6	E	87	68	52	32	11	60
7	A	99	98	93	83	48	89
8	C	90	70	53	37	19	64
9	A	75	61	52	47	33	59
10	E	80	58	44	35	17	56
11	E	99	92	80	62	26	81
12	D	72	52	38	28	14	49
13	B	93	82	72	61	38	76
14	E	66	34	22	20	20	40
15	E	83	51	34	19	9	50
16	B	77	43	29	20	11	46
17	D	93	80	67	52	26	72
18	B	74	48	39	27	17	49

Item No.	Correct Answer	Percent Correct by Score					Total Percent Correct
		5	4	3	2	1	
19	E	83	61	46	32	16	57
20	D	83	57	41	28	14	54
21	A	73	38	27	18	12	42
22	A	27	14	11	6	6	16
23	A	53	20	10	8	6	26
24	E	52	25	19	16	13	31
25	D	94	88	82	73	43	82
26	E	79	56	44	36	21	55
27	E	54	35	32	30	26	39
28	C	68	35	23	18	15	40
29	D	19	11	12	12	12	14
30	E	61	32	24	17	10	36
31	C	71	42	32	22	16	44
32	D	71	30	14	9	8	36
33	D	49	22	16	12	9	27
34	E	92	70	50	34	17	63
35	B	57	35	29	24	20	38