ATTENTION: **All Division I students, START HERE.**
All Division II students – skip the first 10 questions, begin on # 11.

1. Of the following, which quantity is a vector?

   (A) Energy
   (B) Mass
   (C) Average speed
   (D) Temperature
   (E) Linear Momentum

2. In one year, there are approximately $31.5 \times 10^6\ s$. Which of the following representations using metric prefixes is equivalent to this value?

   (A) 31.5 *ks* **(B)** 31.5 *Ms* **(C)** 31.5 *Gs* **(D)** 31.5 *ms* **(E)** 31.5 *ps*

3. A dog starts from rest and runs in a straight line with a constant acceleration of $2.5\ m/s^2$. How much time does it take for the dog to run a distance of $10.0\ m$?

   (A) 8.0 *s* **(B)** 4.0 *s* **(C)** 2.8 *s* **(D)** 2.0 *s* **(E)** 1.4 *s*

4. One mole of an ideal gas has a temperature of $100\ ^\circ C$. If this gas fills the $10.0\ m^3$ volume of a closed container, what is the pressure of the gas?

   (A) 0.821 *Pa*
   (B) 3.06 *Pa*
   (C) 83.1 *Pa*
   (D) 310 *Pa*
   (E) 1.84×10^{24} *Pa*

5. Approximately how much would it cost to keep a $100\ W$ light bulb lit continuously for 1 year at a rate of $\$0.10/kW \cdot hr$?

   (A) \$1 **(B)** \$10 **(C)** \$100 **(D)** \$1000 **(E)** \$100000

6. A positive point charge exerts a force of magnitude F on a negative point charge placed a distance x away. If the distance between the two point charges is halved, what is the magnitude of the new force that the positive point charge exerts on the negative point charge?

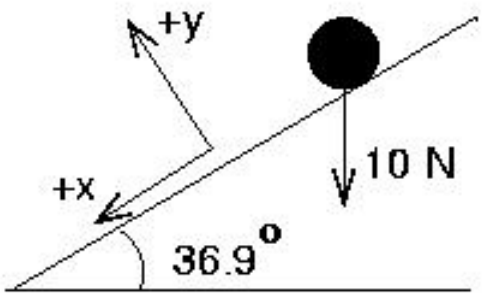
(A) $4F$ **(B)** $2F$ **(C)** F **(D)** $F/2$ **(E)** $F/4$

7. Which of the following types of electromagnetic radiation has the greatest energy per photon?

(A) infrared **(B)** microwave **(C)** FM radio **(D)** AM radio **(E)** violet light

8. An object on an inclined plane has a gravitational force of magnitude $10\ N$ acting on it from the Earth. Which of the following gives the correct components of this gravitational force for the coordinate axes shown in the figure? The y-axis is perpendicular to the incline's surface while the x-axis is parallel to the inclined surface.

	x-component	y-component
(A)	$+6\ N$	$-8\ N$
(B)	$+8\ N$	$-6\ N$
(C)	$-6\ N$	$+8\ N$
(D)	$-8\ N$	$+6\ N$
(E)	$0\ N$	$+10\ N$



9. When a beam of white light passes through a prism, the exiting light is seen as a spectrum of visible colors. This phenomenon is known as

(A) diffraction. **(B)** dispersion. **(C)** interference. **(D)** polarization. **(E)** reflection.

10. Which of the following could be a correct unit for pressure?

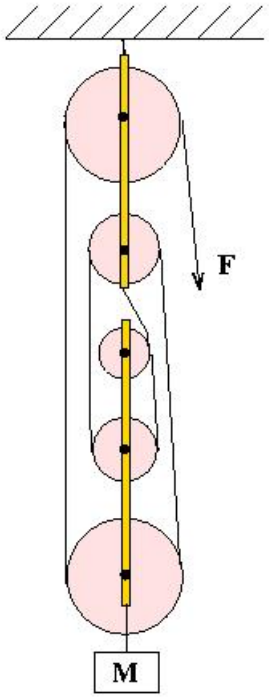
(A) kg/m^2 **(B)** $kg/m \cdot s$ **(C)** kg/s^2 **(D)** $kg/m \cdot s^2$ **(E)** $m \cdot s/kg$

ATTENTION: All Division I students, turn page and continue through question 40.

ATTENTION: All Division II students, START HERE. Numbers 1-10 on your answer sheet should be blank. Your first answer should be for #11.

11. Which person has won a Nobel Prize in physics?

(A) Marie Curie
(B) Isaac Newton
(C) Aristotle
(D) Johannes Kepler
(E) Stephen Hawking



12. What is the average angular speed of the second hand on a clock (in rad/s)?

(A) 6.28 **(B)** 0.105 **(C)** 0.0167 **(D)** 1.745×10^{-3} **(E)** 2.778×10^{-4}

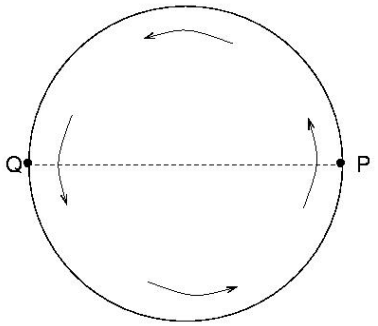
13. What is the ideal mechanical advantage for the pulley system shown to the right?

(A) F/Mg **(B)** Mg/F **(C)** 3 **(D)** 4 **(E)** 5

Questions 14 and 15 refer to the following scenario:
A particle continuously moves in a circular path at constant speed in a counter-clockwise direction. Consider a time interval during which the particle moves along this circular path from point P to point Q. Point Q is exactly half-way around the circle from Point P.

14. What is the direction of the average velocity during this time interval?

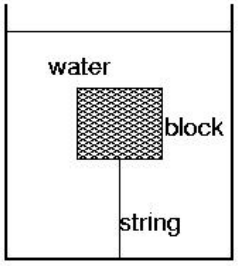
(A) $\rightarrow$ **(B)** $\leftarrow$ **(C)** $\uparrow$ **(D)** $\downarrow$
(E) The average velocity is zero.



15. What is the direction of the average acceleration during this time interval?

(A) $\rightarrow$ **(B)** $\leftarrow$ **(C)** $\uparrow$ **(D)** $\downarrow$
(E) The average acceleration is zero.

16. A block is connected to a light string attached to the bottom of a large container of water. The tension in the string is $3.0\,N$. The gravitational force from the earth on the block is $5.0\,N$. What is the block's volume?



(A) $2.0\times10^{-4}\,m^3$
(B) $3.0\times10^{-4}\,m^3$
(C) $5.0\times10^{-4}\,m^3$
(D) $8.0\times10^{-4}\,m^3$
(E) $1.0\times10^{-3}\,m^3$

17. An ideal red pigment is mixed with an ideal blue pigment. After mixing, what color pigment results?

(A) cyan **(B)** magenta **(C)** yellow **(D)** green **(E)** black

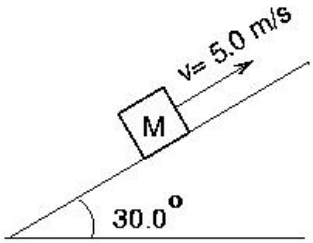
18. A car is moving to the left at $20\,m/s$ while a truck is moving to the right at $25\,m/s$. If the truck emits a sound of frequency $5000\,Hz$, what is the perceived frequency of the sound by the driver of the car? Assume the vehicles are moving directly away from each other on a $20.0^{\circ}C$ day.

(A) $4384\,Hz$ **(B)** $4706\,Hz$ **(C)** $4932\,Hz$ **(D)** $5079\,Hz$ **(E)** $5714\,Hz$

19. Kepler's Second Law about "sweeping out equal areas in equal time" can be derived most directly from which conservation law?

(A) energy
(B) angular momentum
(C) linear momentum
(D) mechanical energy
(E) mass

20. A person pushes a block of mass $M = 6.0\,kg$ with a constant speed of $5.0\,m/s$ straight up a flat surface inclined 30.0° above the horizontal. The coefficient of kinetic friction between the block and the surface is $\mu = 0.40$. What is the net force acting on the block?



(A) $0\,N$ **(B)** $21\,N$ **(C)** $30\,N$ **(D)** $51\,N$ **(E)** $76\,N$

21. Modern telescopes use mirrors, rather than lenses, to form images. One advantage of mirrors over lenses is that the images formed by mirrors are not affected by:

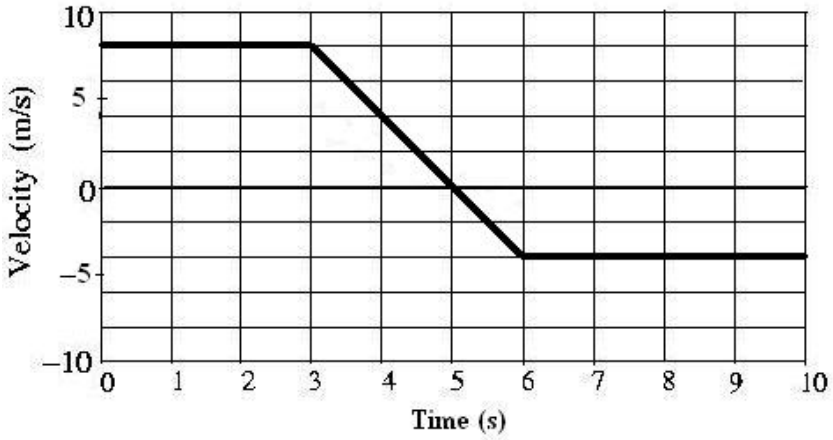
(A) destructive interference
(B) constructive interference
(C) chromatic aberration
(D) spherical aberration
(E) atmospheric refraction

22. In a calorimeter, 20 grams of liquid water at $100\ ^{\circ}C$ is mixed with 50 grams of water vapor at $100\ ^{\circ}C$. The system is allowed to come to equilibrium. Assuming that the calorimeter and the surroundings can be ignored, which of the following best describes the net energy exchange between the vapor and the liquid during the process of coming to equilibrium?

(A) There is no net energy exchange.
(B) Energy is transferred from the vapor to the liquid, vaporizing some of the liquid.
(C) Energy is transferred from the vapor to the liquid, increasing the liquid's temperature.
(D) Energy is transferred from the vapor to the liquid until all of the liquid vaporizes.
(E) Energy is transferred from the liquid to the vapor, condensing some vapor.

Questions 23 and 24 refer to the following scenario:

The velocity vs. time graph for the motion of a car on a straight track is shown in the diagram. The thick line represents the velocity. Assume that the car starts at the origin $x = 0$.



23. At which time is the car the greatest distance from the origin?

(A) $t = 10\,s$ **(B)** $t = 6\,s$ **(C)** $t = 5\,s$ **(D)** $t = 3\,s$ **(E)** $t = 0\,s$

24. What is the average speed of the car for the 10 second interval?

(A) $1.20\,{}^{m}\!/_{s}$ **(B)** $1.40\,{}^{m}\!/_{s}$ **(C)** $3.30\,{}^{m}\!/_{s}$ **(D)** $5.00\,{}^{m}\!/_{s}$ **(E)** $5.40\,{}^{m}\!/_{s}$

25. The following nuclear reaction occurs: ${}^{4}_{2}He + {}^{9}_{4}Be \rightarrow {}^{12}_{6}C + {}^{A}_{Z}X$. What is ${}^{A}_{Z}X$?

(A) a proton
(B) an electron
(C) a positron
(D) an alpha particle
(E) a neutron

26. If the principal quantum number of an electron is $n = 4$, how many possible values of the orbital magnetic quantum number m_l are there for this electron?

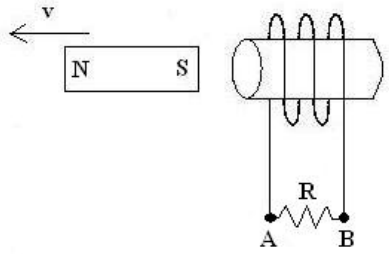
(A) 3 **(B)** 4 **(C)** 7 **(D)** 9 **(E)** 16

27. A tube of length L_1 is open at both ends. A second tube of length L_2 is closed at one end and open at the other end. This second tube resonates at the same fundamental frequency as the first tube. What is the value of L_2 ?

(A) $4L_1$ **(B)** $2L_1$ **(C)** L_1 **(D)** ${}^{1}\!/_{2}\,L_1$ **(E)** ${}^{1}\!/_{4}\,L_1$

28. A diverging lens produces an image of a real object. This image is

(A) virtual, larger than the object, and upright.
(B) virtual, smaller than the object, and upright.
(C) virtual, smaller than the object, and inverted.
(D) real, smaller than the object, and inverted.
(E) real, larger than the object, and inverted.



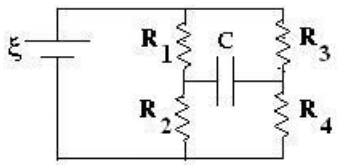
29. A strong bar magnet is held very close to the opening of a solenoid as shown in the diagram. As the magnet is moved away from the solenoid at constant speed, what is the direction of conventional current through the resistor shown and what is the direction of the force on the magnet because of the induced current?

	Current through resistor	Force on Magnet
(A)	From A to B	To the left
(B)	From B to A	To the left
(C)	From A to B	To the right
(D)	From B to A	To the right
(E)	No current	To the right

30. A light beam passes through the air and strikes the surface of a plastic block. Which pair of statements correctly describes the phase changes for the reflected wave and the transmitted wave?

	Reflected wave	Transmitted wave
(A)	90°	90°
(B)	No phase change	180°
(C)	No phase change	No phase change
(D)	180°	180°
(E)	180°	No phase change

31. For the circuit shown, $\xi = 6.0\ V$, $R_1 = 7.0\Omega$, $R_2 = 3.0\Omega$, $R_3 = 6.0\Omega$, and $R_4 = 12.0\Omega$. After operating for a long time, equilibrium is established. What is the voltage across the capacitor at equilibrium?



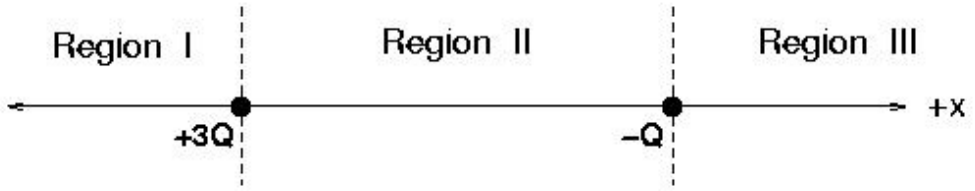
(A) 6.0 V **(B)** 4.2 V **(C)** 3.0 V **(D)** 2.2 V **(E)** 0.2 V

32. On February 20, 2008, there was a total lunar eclipse. What was the phase of the Moon during the eclipse?

(A) New Moon
(B) Full Moon
(C) Dark Moon
(D) Last Quarter
(E) First Quarter

Questions 33 and 34 refer to the following scenario:

Two point charges are fixed on the x-axis in otherwise empty space as shown below.



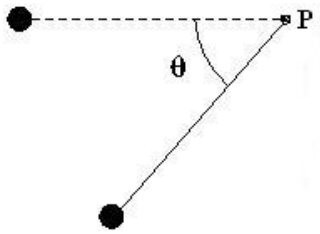
33. In which Region(s) is there a place on the x-axis (aside from infinity) at which the electric potential is equal to zero?

(A) Only in Region II
(B) Only in Region III
(C) In both Regions I and II
(D) In both Regions I and III
(E) In both Regions II and III

34. In which Region(s) is there a place on the x-axis (aside from infinity) at which the electric field is equal to zero?

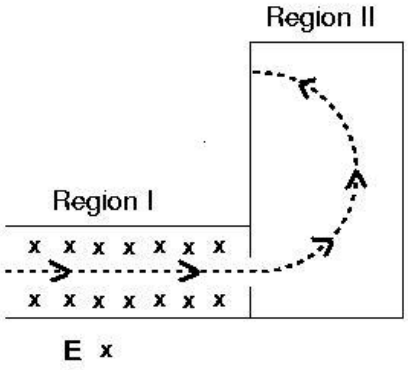
(A) Only in Region II
(B) Only in Region III
(C) In both Regions I and II
(D) In both Regions I and III
(E) In both Regions II and III

35. Astronauts on the Moon perform an experiment with a simple pendulum that is released from the horizontal position at rest. At the moment shown in the diagram with $0^\circ < \theta < 90^\circ$, the total acceleration of the mass may be directed in which of the following ways?



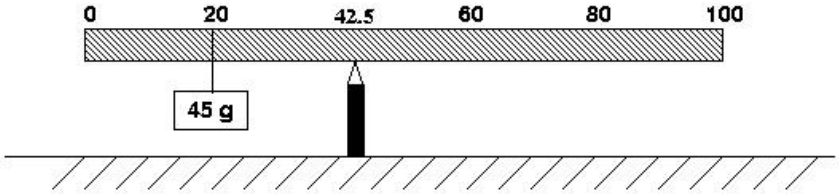
(A) straight to the right
(B) straight to the left
(C) straight upward
(D) straight downward
(E) straight along the connecting string toward point P (the pivot)

36. An electron moves in the plane of the page through two regions of space along the dotted-line trajectory shown in the figure. There is a uniform electric field in Region I directed into the plane of the page (as shown). There is no electric field in Region II. What is a necessary direction of the magnetic field in regions I and II? Ignore gravitational forces.



	Region I	Region II
(A)	Down the plane of the page	Up the plane of the page
(B)	Up the plane of the page	Into the plane of the page
(C)	Up the plane of the page	Out of the plane of the page
(D)	Down the plane of the page	Out of the plane of the page
(E)	Into the plane of the page	Up the plane of the page

37. A uniform meter stick has a $45.0\,g$ mass placed at the $20\,cm$ mark as shown in the figure. If a pivot is placed at the $42.5\,cm$ mark and the meter stick remains horizontal in static equilibrium, what is the mass of the meter stick?



(A) $18.0\,g$ **(B)** $45.0\,g$ **(C)** $72.0\,g$ **(D)** $120.0\,g$ **(E)** $135.0\,g$

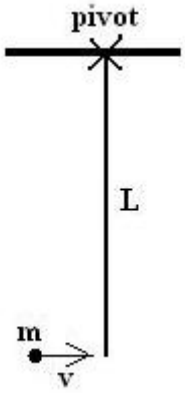
38. A $1200\,kg$ satellite orbits Planet X in a circular orbit with a constant speed of $5.00\times10^{3}\,{}^{m}\!/_{s}$. The radius of orbit is $7.50\times10^{7}\,m$. What is the magnitude of the gravitational force exerted on the satellite by Planet X?

(A) $400\,N$ **(B)** $200\,N$ **(C)** $0.080\,N$ **(D)** $0.0127\,N$ **(E)** More information is required to answer this question.

39. An ideal gas is enclosed in a container. The volume of the container is reduced to half the original volume at constant temperature. According to kinetic theory, what is the best explanation for the increase in pressure created by the gas?

(A) The average speed of the gas particles decreases, but they hit the container walls more frequently.
(B) The average speed of the gas particles is unchanged, but they hit the container walls more frequently.
(C) The average speed of the gas particles increases as does the frequency with which they hit the container walls.
(D) The average speed of the gas particles increases, overcoming the decreased frequency that they hit the container walls.
(E) The internal energy of the gas increases.

40. A point particle of mass m collides with a thin rod pivoted at one end. The rod has mass $M = 2m$, length L, and moment of inertia $I = \frac{1}{3}ML^2$. The particle moves horizontally with speed V when it hits the bottom of the rod and sticks to it. What is the speed of the particle immediately after collision?



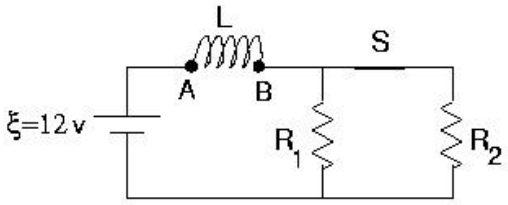
(A) $\frac{1}{3}V$ **(B)** $\frac{1}{\sqrt{3}}V$ **(C)** $\frac{3}{5}V$ **(D)** $\frac{3}{4}V$ **(E)** $\frac{\sqrt{3}}{2}V$

IMPORTANT: All Division I students STOP HERE. Your last answer should be number 40. Numbers 41-50 should remain blank for Division I students.
All Division II students continue to Questions 41 – 50.

ATTENTION: All Division I students, STOP HERE.
All Division II students, continue to question 50.

41. The circuit shown has been operating for a long time. The instant after the switch in the circuit labeled S is *opened*, what is the voltage across the inductor V_L and which labeled point (A or B) of the inductor is at a higher potential? Take $R_1 = 4.0\,\Omega$, $R_2 = 8.0\,\Omega$, and $L = 2.5\,H$.

(A) $V_L = 30\ V$; Points A and B are at equal potentials.
(B) $V_L = 12\ V$; Point A is at the higher potential.
(C) $V_L = 12\ V$; Point B is at the higher potential.
(D) $V_L = 6\ V$; Point A is at the higher potential.
(E) $V_L = 6\ V$; Point B is at the higher potential.



42. A parallel-plate capacitor is connected to a battery. Without disconnecting the capacitor, a student pulls the capacitor's plates apart so that the plate separation doubles. As a result of this action, what happens to the voltage across the capacitor and the energy stored by the capacitor?

(A) the voltage doubles; the energy stays the same
(B) the voltage halves; the energy doubles
(C) the voltage doubles; the energy halves
(D) the voltage stays the same; the energy halves
(E) the voltage stays the same; the energy doubles

43. Unpolarized light of intensity I_0 enters a polarizer-analyzer system in which the angle between the transmission axes of the polarizer and analyzer is 30°. What is the intensity of the light leaving the analyzer?

(A) $\frac{3}{8} I_0$ **(B)** $\frac{1}{8} I_0$ **(C)** $\frac{3}{4} I_0$ **(D)** $\frac{1}{4} I_0$ **(E)** $\frac{1}{2} I_0$

44. A mole of a monatomic ideal gas has pressure P, volume V, and temperature T. Which of the following processes would result in the greatest amount of energy added to the gas from heat?

(A) A process doubling the temperature at constant pressure.
(B) An adiabatic free expansion doubling the volume.
(C) A process doubling the pressure at constant volume.
(D) An adiabatic expansion doubling the volume.
(E) A process doubling the volume at constant temperature.

45. Electron #1 moves with speed $0.30c$ where c is the speed of light. Electron #2 moves with speed $0.60c$. What is the ratio of the kinetic energy of electron #2 to electron #1?

(A) 1.19 **(B)** 1.32 **(C)** 2.00 **(D)** 4.00 **(E)** 5.18

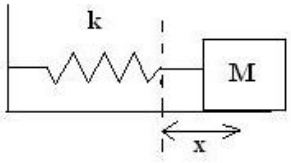
46. A traveling wave has the form $y(x,t) = 3.0\sin(2.5x - 5.0t)$ where all quantities given are in MKS units, x is position, and t represents time. What is the period of the wave (in seconds)?

(A) 2.00 **(B)** 1.26 **(C)** 1.00 **(D)** 0.63 **(E)** 0.20

47. A radioactive sample decays with a half-life of $2.0\,yr$. Approximately how much time must pass so that only $1/3$ of the original sample remains?

(A) $6.0\,yr$ **(B)** $3.4\,yr$ **(C)** $3.2\,yr$ **(D)** $3.0\,yr$ **(E)** $2.8\,yr$

48. A block of mass M on a horizontal surface is connected to the end of a massless spring of spring constant k. The block is pulled a distance x from equilibrium and when released from rest, the block moves toward equilibrium. What minimum coefficient of kinetic friction between the surface and the block would prevent the block from returning to equilibrium with non-zero speed?

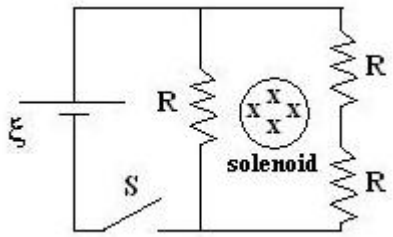


(A) $\frac{kx^2}{2Mg}$ **(B)** $\frac{kx}{Mg}$ **(C)** $\frac{kx}{2Mg}$ **(D)** $\frac{Mg}{2kx}$ **(E)** $\frac{k}{4Mgx}$

49. A circuit consists of a resistor, capacitor, and inductor connected in series to an AC source. As the source frequency increases, the current in the circuit decreases. Which statement about the circuit is **NOT** correct as the source frequency increases?

(A) The impedance of the circuit increases.
(B) The circuit is said to become more capacitive than inductive.
(C) The phase angle for the circuit becomes more positive.
(D) The inductive reactance increases.
(E) The total power from the source decreases.

50. An infinitely long solenoid passes through the circuit as shown. The magnetic field of the solenoid, directed into the plane of the page, is weakening which produces a constant emf of magnitude ξ for a closed loop around the outside of the solenoid. Once equilibrium is established in this circuit, what is the voltage across the switch S?



(A) 0 **(B)** $\frac{1}{3}\xi$ **(C)** $\frac{2}{3}\xi$ **(D)** ξ **(E)** $\frac{4}{3}\xi$