Poire

$E = Mc^2$

$E = \frac{hc}{\lambda}$

$mc^2 = \frac{hc}{\lambda}$

$\lambda = \frac{h}{mc}$

$\lambda = \frac{h}{mv}$

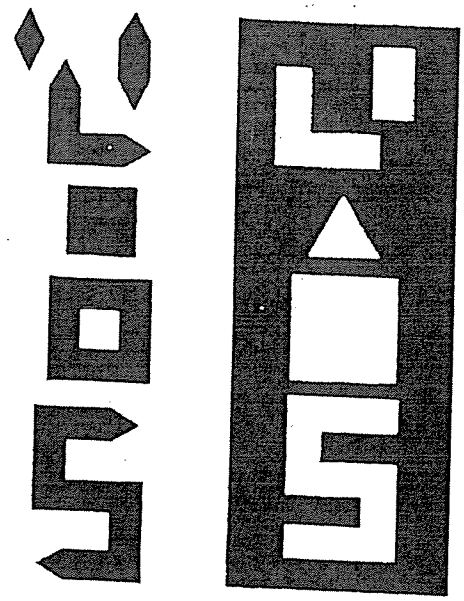
$\lambda = \frac{h}{p}$

Procedure

This puzzle shows the challenge that particle physicists face. Imagine that the puzzle presents information that was obtained about particles from an accelerator. The black figures represent objects that were observed, while the objects shown in white have not been observed. In this puzzle, "objects" are all two-dimensional shapes, and "interactions" are ways in which they can combine.

The shapes that are not observed provide important clues to the answers. *Note:* You need to answer both questions to explain why the objects that are not observed are not possible.

- Identify the shapes which are present.
- State the rules for connecting these shapes.



Source: Puzzle adapted from Helen Quinn, "Of Quarks, Anti-quarks, and glue." *The Stanford Magazine*, Fall, 1983, p.29.

Chapter One Assessments

Part A Questions

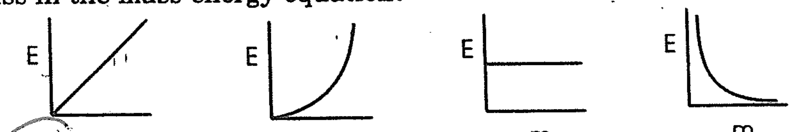
1 Compared to the gravitational force between two nucleons in an atom, the strong nuclear force between the nucleons is
(1) weaker and has a shorter range
(2) weaker and has a longer range
(3) stronger and has a shorter range
(4) stronger and has a longer range

2 A baryon may have a charge of
(1) $-\frac{1}{3}$ e (2) 0 e (3) $+\frac{2}{3}$ e (4) $+\frac{4}{3}$ e

3 Which force between the protons in an atom will have the greatest magnitude?
(1) gravitational force
(2) electromagnetic force
(3) strong nuclear force
(4) magnetic force

4 Which one of the following statements is true concerning the proton?
(1) The proton is composed of two up quarks and a down quark.
(2) The proton is composed of two down quarks and an up quark.
(3) The proton is composed of a down quark and an up anti-quark.
(4) The proton is composed of an up quark and a down anti-quark.

5 Which graph best represents the relationship between energy and mass in the mass-energy equation?



(1) (2) (3) (4)

6 All particles can be classified into
(1) leptons and quarks
(2) hadrons and leptons
(3) baryons and leptons
(4) mesons and baryons

7 Particles composed of quarks are
(1) photons and mesons
(2) leptons and baryons
(3) baryons and mesons
(4) mesons and leptons

8 Protons and neutrons are composed of smaller particles called
(1) quarks
(2) baryons
(3) alpha particles
(4) bosons

9 Which type of force overcomes the repulsive electrostatic force between protons in the nucleus of an atom?
(1) magnetic
(2) nuclear
(3) gravitational
(4) centrifugal

10 The subatomic particles that make up protons are called
(1) hyperons (2) baryons (3) positrons (4) quarks

11 Which one of the following is equivalent to 2.0 m?
(1) 2.0×10^4 cm
(2) 2.0×10^{-2} cm
(3) 2.0×10^2 cm
(4) 2.0×10^3 cm

12 Which one of the following is equivalent to 24.8 m?
(1) 2.48×10^1 m (2) 2.48×10^2 m (3) 2.48×10^{-1} m (4) 2.48×10^0 m

13 Which one of the following is the longest length?
(1) 10^0 meters
(2) 10^2 centimeters
(3) 10^4 millimeters
(4) 10^5 micrometers

14 Which of the fundamental forces is responsible for paint adhering to a wall?
(1) strong
(2) weak
(3) gravity
(4) electromagnetic

15 Which of the fundamental forces is evident in radioactive decay?
(1) gravity
(2) strong
(3) weak
(4) electromagnetic

16 What is the approximate diameter of a dinner plate?
(1) 0.0025 m (2) 0.025 m (3) 0.25 m (4) 2.5 m

17 The length of a high school physics classroom is probably closest to
(1) 10^{-2} m (2) 10^{-1} m (3) 10^{1} m (4) 10^{4} m

18 A mass of one kilogram of nickels has a monetary value in United States dollars of approximately
(1) $1.00 (2) $0.10 (3) $10.00 (4) $1000.00

PART B QUESTIONS

19 How much energy is released when 1.00×10^{-3} kilogram of matter is converted to energy?
(1) 3.00×10^{5} J
(2) 3.00×10^{8} J
(3) 9.00×10^{13} J
(4) 9.00×10^{16} J

20 Approximately how much energy is produced when 0.500 atomic mass unit of matter is completely converted into energy?
(1) 9.31 MeV
(2) 9.31×10^{2} MeV
(3) 4.65 MeV
(4) 4.65×10^{2} MeV

$E=mc^2$
$=.5(3\times10^8 m/s)^2$

21 If the mass of one proton is totally converted into energy, it will yield a total energy of
(1) 5.10×10^{-19} J
(2) 1.50×10^{-10} J
(3) 9.31×10^{8} J
(4) 9.00×10^{16}J

22 Approximately how much energy would be generated if the mass in a nucleus of a $^{2}_{1}H$ atom were completely converted to energy? [The mass of $^{2}_{1}H$ is 2.00 atomic mass units.]
(1) 3.21×10^{-19} J
(2) 2.98×10^{-10} J
(3) 9.31×10^{2} MeV
(4) 9.00×10^{3} MeV

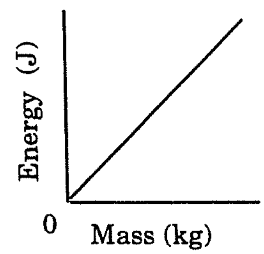
23 The length of a lake is 15.5 km. What is the length of the lake in m?
(1) 1.55×10^{4}m
(2) 3.06×10^{5}m
(3) 1.55×10^{6}m
(4) 1.55×10^{7}m

24 A bead has a mass of one *milli*gram. Which one of the following statements indicates the correct mass of the bead in grams?
(1) The bead has a mass of 1×10^{3} grams.
(2) The bead has a mass of 1×10^{-1} grams.
(3) The bead has a mass of 1×10^{-3} grams.
(4) The bead has a mass of 1×10^{-6} grams.

25 A physics text has 1060 pages and is 33.5 millimeters thick between the inside front cover and the inside back cover. What is the thickness of a page? The answer should be expressed in scientific notation with the correct number of significant figures.
(1) 3.55×10^{-4} m
(2) 3.2×10^{-3} m
(3) 3.6×10^{-6} m
(4) 3.16×10^{-5} m

26 The graph at the right represents the relationship between mass and its energy equivalent. The slope of the graph represents: [1]

Energy Equivalent vs. Mass



c^2

27 The composition of a meson is: [1]

quark & anti-quark

28 Which quarks combine to form a neutron? [1]

udd

29 A particle with the quark composition "down down charm" would have what electrical charge? [1]

0e

30 How many particles combine to form a baryon? [1]

3 Q-k

31 List the four fundamental forces in order of strength, beginning with the weakest force. [4]

a grav.
b weak nucl
c EM
d strong nucl.

PART C QUESTIONS

32 How much more energy in joules would a proton yield than an electron if both were completely converted into energy? [Show all work including formula, and substitutions with units.] [2]

$E = mc^2$
Prot. 1.5×10^{-10} J
Elect 8.2×10^{-14} J

33 If the mass of one neutron is totally converted into energy, determine the energy in both joules and MeV. [Show all work including formula, and substitutions with units.] [2]

931 MeV

Chapter Eighteen Assessments

Part A Questions

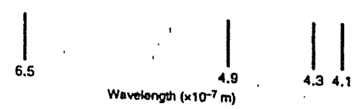
1 In which part of the electromagnetic spectrum does a photon have the greatest energy?
(1) red (2) infrared (3) violet (4) ultraviolet

2 During a collision between a photon and an electron, there is conservation of
(1) energy, only
(2) momentum, only
(3) both energy and momentum
(4) neither energy nor momentum

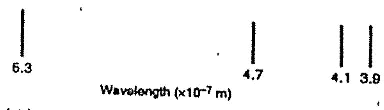
3 The momentum of a photon is inversely proportional to the photon's
(1) frequency
(2) mass
(3) weight
(4) wavelength

4 The four-line Balmer series spectrum shown below is emitted by a hydrogen gas sample in a laboratory. A star moving away from Earth also emits a hydrogen spectrum.

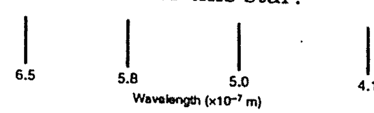
Lines in Hydrogen Spectrum



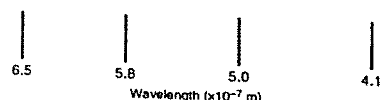
Which Spectrum might be observed on Earth for this star?



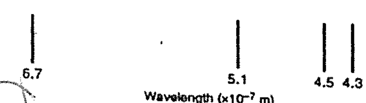
(1)



(3)



(2)



(4)

5 Which phenomenon can be explained by both the particle model and wave model?
(1) reflection
(2) diffraction
(3) polarization
(4) interference

6 Light demonstrates the characteristics of
(1) particles, only
(2) waves, only
(3) both particles and waves
(4) neither particles nor waves

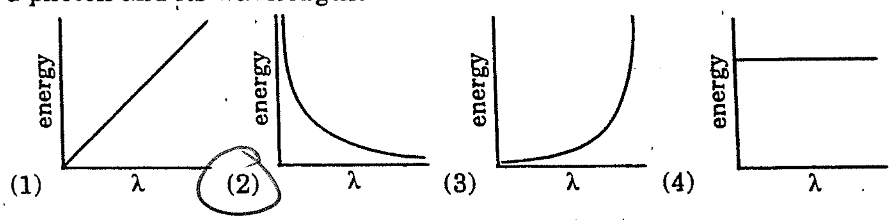
7 The photon model of light is more appropriate than the wave model in explaining
(1) interference
(2) refraction
(3) polarization
(4) photoelectric emission

Note: Question 8 has only 3 answer choices.

8 Interference and diffraction can be explained by
(1) the wave theory, only
(2) the particle theory, only
(3) neither the wave nor particle theory

9 The energy of a photon varies
(1) directly as the wavelength
(2) directly as the frequency
(3) inversely as the frequency
(4) inversely as the square of the frequency

10 Which graph best represents the relationship between the energy of a photon and its wavelength?



11 If the wave properties of a particle are difficult to observe, it is probably due to the particle's
(1) small size
(2) large momentum
(3) low momentum
(4) high charge

Note: Questions 12 and 13 have only 3 answer choices.

12 As the wavelength of a ray of light increases, the momentum of the photons of the light ray will
(1) decrease (2) increase (3) remain the same

13 As the frequency of a photon increases, its momentum
(1) decrease (2) increase (3) remain the same

14 According to the quantum theory of light, the energy of light is carried in discrete units called
(1) alpha particles
(2) protons
(3) photons
(4) photoelectrons

15 Which is conserved when a photon collides with an electron?
(1) velocity
(2) momentum, only
(3) energy, only
(4) momentum and energy

16 Which color of light has the greatest energy per photon?
(1) red (2) green (3) blue (4) violet

$E = hf$

PART B QUESTIONS

17 What is the minimum energy required to excite a mercury atom initially in the ground state? [1] 4.64 eV

18 The electron in a hydrogen atom drops from energy level $n = 2$ to energy level $n = 1$ by emitting a photon having an energy of approximately [1] _____ joules 10.2eV → 10.2eV × 1.6×10^-19 J / 1eV

19 A hydrogen atom could have an electron energy level transition from $n = 2$ to $n = 3$ by absorbing a photon having an energy of [1] 1.89 eV

20 What is the approximate matter wavelength of a 0.30-kilogram tennis ball moving at a speed of 30. meters per second? [1] _______ m

7.4×10^-35

21 If the momentum of a particle is 1.8×10^{-22} kilogram-meter per second, its matter wavelength is approximately [1] _______ m

3.7×10^-12

22 Blue light has a frequency of approximately 6.0×10^{14} hertz. A photon of blue light will have an energy of approximately [1] ______ J

4×10^-19

23 What is the energy of a photon with a frequency of 5.0×10^{15} hertz [1] _______ J

3.3×10^-18 J

24 The momentum of a photon with a wavelength of 5.9×10^{-7} meter is [1] _______ kg m/s

1.1×10^-27

25 What is the approximate matter wavelength of a 0.500-kilogram tennis ball moving at a speed of 300. meters per second? [1] 4.4×10^-36 m

26 What is the energy of a photon with a frequency of 3.00×10^{13} hertz? [1] _______ J 2×10^-20 J

27 The energy of a photon which has a frequency of 3.3×10^{34} hertz is approximately [1] __________ J 22.5

28 What is the wavelength of the matter wave associated with a bird of 1.0-kilogram mass flying at 2.0 meters per second? [1] _______ m

3.3×10^-34 m

29 An atom changing from an energy state of -0.54 eV to an energy state of -0.85 eV will emit a photon whose energy is [1] _______ eV

.31 eV

PART C QUESTIONS

Base your answers to questions 30 and 31 on the information below.

An electron is accelerated from rest to a speed of 2.0×10^6 meters per second.

30 How much kinetic energy is gained by the electron as it is accelerated from rest to this speed? [Show all calculations, including the equation and substitution with units.] [2]

1.6×10^-19 J

31 What is the matter wavelength of the electron after it is accelerated to this speed? [Show all calculations, including the equations and substitutions with units.] [2]

3.6×10^-10 m

Base your answers to questions 32 through 34 on the information below.

A hydrogen atom emits a 2.55-electronvolt photon as its electron changes from one energy level to another.

32 Express the energy of the emitted photon in joules. [1]

4.08×10^-19 J

33 Determine the frequency of the emitted photon. [Show all calculations, including the equation and the substitution with units.] [2]

6.2×10^14 Hz

34 Using the *Reference Tables for Physical Setting: Physics*, determine the energy level change for the electron. [2]

2.55 eV

4/10

Date ______________ Period ______________ Name ______________________

56 Transparency Worksheet

Use with Chapter 30, Section 30.2.

Subatomic Particles

1. What is the charge on an up quark? $+\frac{2}{3}e$

2. What is the charge on a down quark? $-\frac{1}{3}e$

3. What combination of quarks make up a proton?
uud

4. What is the charge on a proton? Explain in terms of the quarks that comprise a proton.
$+\frac{2e}{3} + \frac{+2}{3} - \frac{1}{3} = +1$

5. What combination of quarks make up a neutron?
udd
$+\frac{2}{3} - \frac{1}{3} - \frac{1}{3} = 0$

6. What is the charge on a neutron? Explain in terms of the quarks that comprise a neutron.

7. Which is more energetic, a bottom quark or a strange quark?
bottom

8. Which is less energetic, a tau lepton or a muon?
moun

9. From which particles is the everyday world made?
ups/downs

Standard Model of
FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (quantum chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactions even though not part of the "Standard Model."

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

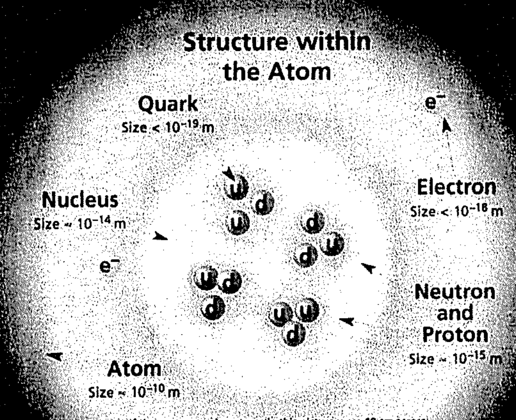
Leptons spin = 1/2		
Flavor	Mass GeV/c^2	Electric charge
ν_e electron neutrino	<1×10^{-8}	0
e electron	0.000511	−1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	−1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	−1

Quarks spin = 1/2		
Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
d down	0.006	−1/3
c charm	1.3	2/3
s strange	0.1	−1/3
t top	175	2/3
b bottom	4.3	−1/3

Spin is the intrinsic angular momentum of particles. Spin is given in units of ħ, which is the quantum unit of angular momentum, where $\hbar = h/2\pi = 6.58\times10^{-25}$ GeV s = 1.05×10^{-34} J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is $1.60\cdot10^{-19}$ coulombs.

The **energy** unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c^2 (remember $E = mc^2$), where 1 GeV = 10^9 eV = 1.60×10^{-10} joule. The mass of the proton is 0.938 GeV/c^2 = 1.67×10^{-27} kg.



If the protons and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1		
Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.4	−1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1		
Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Color Charge

Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons. Just as electrically-charged particles interact by exchanging photons, in strong interactions color-charged particles interact by exchanging gluons. Leptons, photons, and **W** and **Z** bosons have no strong interactions and hence no color charge.

Quarks Confined in Mesons and Baryons

One cannot isolate quarks and gluons; they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs (see figure below). The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge. Two types of hadrons have been observed in nature: **mesons** $q\bar{q}$ and **baryons** qqq.

Residual Strong Interaction

The strong binding of color-neutral protons and neutrons to form nuclei is due to residual strong interactions between their color-charged constituents. It is similar to the residual electrical interaction that binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.

PROPERTIES OF THE INTERACTIONS

Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic (Electroweak)	Strong: Fundamental	Strong: Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength relative to electromag for two u quarks at: 10^{-18} m	10^{-41}	0.8	1	25	Not applicable to quarks
Strength relative to electromag for two u quarks at: 3×10^{-17} m	10^{-41}	10^{-4}	1	60	Not applicable to quarks
for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$ — Baryons are fermionic hadrons. There are about 120 types of baryons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	−1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	−1	1.672	3/2

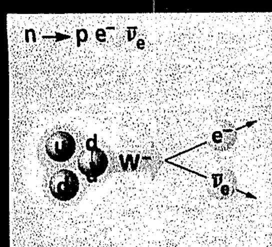
Mesons $q\bar{q}$ — Mesons are bosonic hadrons. There are about 140 types of mesons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	−1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2.980	0

Matter and Antimatter

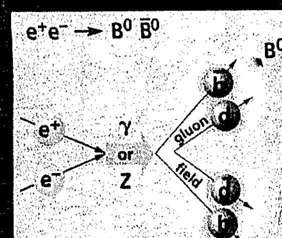
For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or − charge is shown). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0, γ, and $\eta_c = c\bar{c}$, but not $K^0 = d\bar{s}$) are their own antiparticles.

Figures

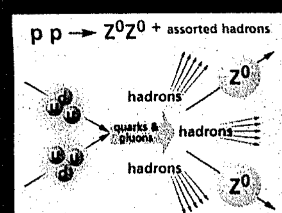
These diagrams are an artist's conception of physical processes. They are *not* exact and have *no* meaningful scale. Green shaded areas represent the cloud of gluons or the gluon field, and red lines the quark paths.



A neutron decays to a proton, an electron, and an antineutrino via a virtual (mediating) W boson. This is neutron β decay.



An electron and positron (antielectron) colliding at high energy can annihilate to produce B^0 and $\bar{B}^0$ mesons via a virtual Z boson or a virtual photon.



Two protons colliding at high energy can produce various hadrons plus very high mass particles such as Z bosons. Events such as this one are rare but can yield vital clues to the structure of matter.

The Particle Adventure

Visit the award-winning web feature *The Particle Adventure* at
http://ParticleAdventure.org

This chart has been made possible by the generous support of:

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