

# Quantum Quandary

2025 Washington Science Olympiad State Test

## KEY

Names: \_\_\_\_\_

School: \_\_\_\_\_

Team Number: \_\_\_\_\_

Score: \_\_\_\_\_

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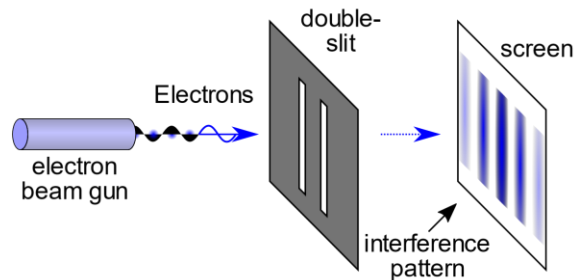
| Page  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | total |
|-------|----|----|----|----|----|----|----|----|----|----|-------|
| Score | 20 | 10 | 20 | 10 | 18 | 15 | 13 | 14 | 16 | 14 | 150   |
| Max   | 20 | 10 | 20 | 10 | 18 | 15 | 13 | 14 | 16 | 14 | 150   |

This is a long and challenging test. We do not anticipate that most teams will complete the test in the allowed 50 minutes. We recommend that you start by reading all the questions and select those on which you can best succeed. If and when you complete those questions, move on to others that are more challenging to you.

- We will grant partial credit in many of the questions based demonstrating that you have basic comprehension of the specific topics. Show your work or the grader(s) will not have any chance to assess your level of knowledge.
- We have attempted to provide adequate space for your response. If you need additional paper, please get some from the supervisor in the test room, and identify which questions is being answered on each and all additional sheets.
- If you need clarification on any question, and the supervisor decides that all students should hear the clarification you are seeking, they will announce the question and clarification to the entire group.

## Basic concepts and history of Quantum Physics

1. Consider a double slit experiment with a point source of electrons or photons
  - a. [2pts] What is the name of the man who first performed this experiment?
    - a. Lester Germer
    - b. Thomas Young
    - c. Clinton Davisson
    - d. George Thomson
  - b. [8pts] Draw an experimental set-up



+2 points for beam electrons or photons  
+2 points for double slit  
+2 points for interference pattern of waves  
+ 2 points for screen

- c. [2pts] What do the results of this experiment demonstrate?
  - a. That an electron beam is not coherent
  - b. That electrons act like waves
  - c. That electrons can pass through the barrier at spots between the slits
  - d. That electrons show aspects of particle and wave behaviors
- d. [4pts] Describe how the results of experiment change if sensing is provided for photon/electron detection at a slit.

If detectors are used to determine which slit the electrons passes through, the interference pattern is lost. The wave function collapses

+4 points for similar answer

2. [4pts] What must be true about two operators, if it is possible to know both observables at the same time?

They share a set of common eigenfunctions (states)

+4 points for similar answers

3. [2pts] What aspect of Quantum Mechanics did the Einstein-Podolsky-Rosen Paradox question?

a. Entanglement

b. Interference

c. Decoherence

d. **Superposition**

4. [3pts] What is the minimum positional uncertainty for a 730 nm photon that has a momentum uncertainty of 0.3%?

Momentum of photon is  $9.07680842E-28$

Uncertainty in momentum is  $0.003 * 9.07680842E-28 = 2.72304253E-30$

$\Delta x = 1.054571817E-34 / 2 * 2.72304253E-30 = \mathbf{1.93638514E-5 \text{ meters}}$

+3 points if correct answer( if answer is close and rounded, give full points)

+ 1 points if incorrect answer but relevant work

+0 points if incorrect answer and no relevant work

5. [2pts] What transformation does the parity operator correspond to?

a. Translation

b. Rotation

c. **Reflection**

d. Dilation

6. [3pts] Consider the following superposition

$$\theta = \frac{1}{\sqrt{5}}f(x) + \frac{\sqrt{3}}{7}g(x)$$

What factor N must you multiply  $\theta$  by to normalize it?

$$N^2 * (1/5 + 3/49) = 1$$

$$N^2 = 245/64$$

$$\mathbf{N = 1.956 \text{ or } 7*\text{sqrt}(5)/8}$$

## Atomic and Particle Physics

7. Answer the following questions about the photoelectric effect.

a. [2pts] The photoelectric effect shows light acting like a...

a. Particle

b. Wave

b. [2pts] What differentiates the photovoltaic effect from the photoelectric effect?

a. The photovoltaic effect results in electrons freed from the surface of an illuminated plate.

b. The photovoltaic effect results in the potential energy between the surfaces of the illuminated plate

c. The photoelectric effect can only be generated in semiconductor materials with a bandgap between .8 and 1.9V

d. None of the other answers

8. [10 pts, 2pts each] Name the 5 Bosons that have been observed experimentally.

1. Photon

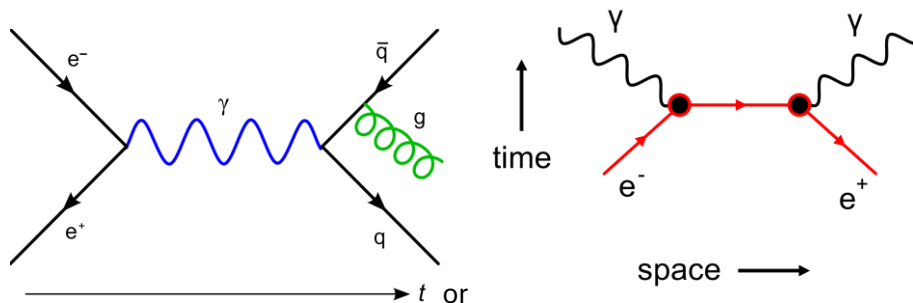
2. Gluon

3. W boson

4. Z boson

5. Higgs

9. [6 pts] Draw the Feynman diagram of an electron positron annihilation process.

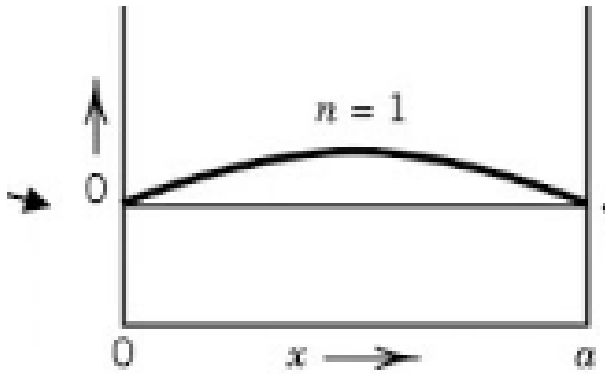


+1 for each correct line with correct label (5pts max)

+1 The whole drawing is correct

10. A non-relativistic electron of mass  $m$  is confined in vacuum between two metal plates separated by a distance  $L$ .

a. [4pts] Draw how the electron wave would look like between the plates at its minimum possible kinetic energy?



+2 points if curve is drawn incorrectly

+4 points if everything is correct

b. [3pts] What is the average momentum of the electron?

$$\langle p \rangle = 0$$

c. [3 pts] What is the formula for the energy of the electron in the  $n$ th mode?

$$KE = n^2 * h^2 / 8 * m * L^2$$

## Statistical Physics

11. [2 pt] The First Law of Thermodynamics describes the conservation of Energy. Write an equation that defines the Total Energy ( $E_{\text{total}}$ ) of a system.

$$E_{\text{Total}} = KE_{\text{system}} + PE_{\text{system}} + U_{\text{system}}$$

12. [4 pt] The Second Law of Thermodynamics describes the irreversibility of natural processes. The equation  $\delta Q = T dS$  is a statement of the 2<sup>nd</sup> Law for complete systems. If  $\delta Q$  is heat transfer and  $T$  is absolute temperature, what does  $dS$  symbolize and what limit does the 2<sup>nd</sup> Law define for  $dS$ ?

**$dS$  is the change in Entropy within the system. It must be greater than or equal to zero.**

**+2 points for what  $dS$  is**

**+2 points for limit of  $dS$**

13. [4 pts] The third Law of Thermodynamics describes absolute limits for systems in which all kinetic and potential energy has been removed from the system. This Law is captured in the equation  $S = k_B \ln \Omega$ . It defines the limit at absolute zero temperature or Ground state. The term  $S$  is consistent with the 2<sup>nd</sup> Law definition above,  $k_B$  is the Boltzmann constant. What does  $\Omega$  symbolize? What is  $S$  at 0K?

**$\Omega$  Symbolizes the number of microstates possible for the system. If the system is a perfect crystal with only a single microstate, the Entropy of that crystal could be  $\ln(1) = 0$  so it is possible to have a crystal with 0 entropy at absolute zero temperature.**

**+2 points for what  $\Omega$  Symbolizes**

**+2 points for  $S$  at 0 K**

14. [2pts] Which material has the largest specific heat capacity?

a. Brass

b. Gold

c. Iron

**d. Aluminum**

15. [2pts] How many vibrational degrees of freedom does a  $\text{CH}_4$  molecule have?

a. 8

**b. 9**

c. 10

d. 11

16. [2 pts] For a spontaneous process in an isolated system, what is the change in entropy?

a.  $\Delta S < 0$

b.  $\Delta S = 0$

**c.  $\Delta S > 0$**

17. [2pts] A reversible process can occur in a closed system?

**a. True**

b. False

18. These questions all relate to a Carnot cycle engine that follows the following cycle path. The working fluid is a monatomic ideal gas. ( $PV=nRT$  is valid.) The portions of the cycle marked

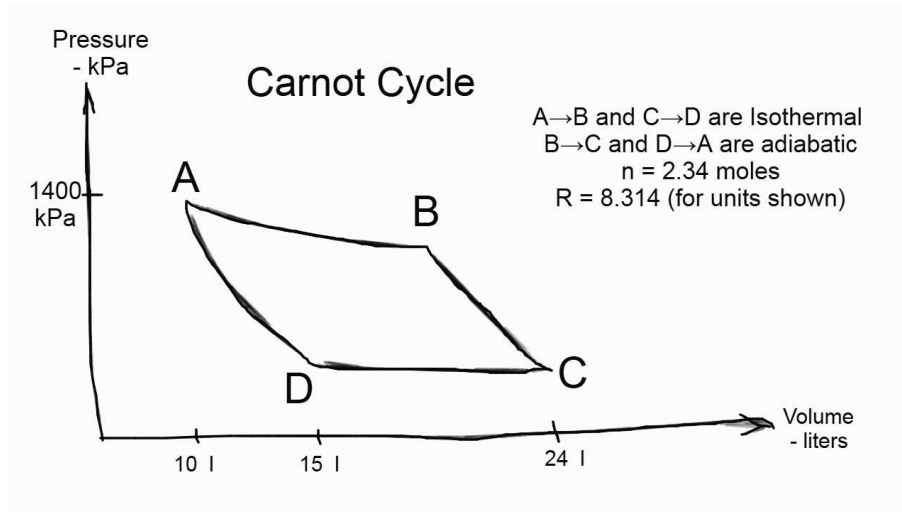
$A \rightarrow B$  and  $C \rightarrow D$  are isothermal. ( $T_A = T_B$  and  $T_C = T_D$ .) The portions of the cycle marked  $B \rightarrow C$  and  $D \rightarrow A$  are adiabatic. ( $PV^\gamma = \text{Constant}, \gamma = 5/3$ .) Restrict answers to 3 significant figures.

For each answer:

+3 if answer is correct

+1 if answer is incorrect but showed work

+0 if answer is incorrect and no relevant work shown



a. [3 pts] What is the Temperature at point B ( $T_B$ )?

$$T_B = T_A = P_A V_A / nR = 720 \text{ C or } 993 \text{ K}$$

b. [3 pts] What is the Pressure at point D ( $P_D$ )?

$$P_D = P_A V_A / V_D = 712 \text{ kPa}$$

c. [3 pts] What is the Temperature at point C ( $T_C$ )?

$$T_C = T_D = P_D V_D / nR = 549 \text{ C or } 822 \text{ K}$$

d. [3 pts] What is the Pressure at point C ( $P_C$ )?

$$P = nRT/V = 445 \text{ kPa}$$

e. [3 pts] What is the Volume at Point B ( $V_B$ )?

$$V_B = (T_C / T_B)^{3/2} * V_C = 16 \text{ L}$$

## Solid-State Material Science

19. [2pts] What is the bandgap energy of a good conductor? **0 eV**

20. [2pts] What is the bandgap energy of a good insulator? **> 3 eV**

21. [2pts] What would be a typical bandgap energy of Single Crystalline Silicon?

- a. 0.8 eV
- b. 1.1 eV
- c. 1.4 eV
- d. 1.7 eV

22. [3pts] The ratio of electrons in the conduction band to valence band of a semiconductor is  $5.27 \times 10^{-36}$  at 300K. Predict the band gap energy.

$$5.27 \times 10^{-36} = e^{-(E/kb \cdot 300)}$$

$$E = \ln(5.27 \times 10^{-36}) \cdot kb \cdot 300 = 2.1 \text{ eV}$$

+3 if answer is correct

+1 if answer is incorrect but showed work

+0 if answer is incorrect and no relevant work shown

23. [2pts] If a new superconductor was discovered that functioned at a temperature of 100K, what type would it be classified as?

- a. Type I
- b. Type II

24. [2pts] If there are magnetic fields going through a material, what happens to that magnetic field when the material transitions into a superconductor?

- a. The magnetic field is expelled from material
- b. The magnetic field is strengthened
- c. The magnetic field is weakened
- d. Nothing happens to the magnetic field

25. [2pts] For a two-level system with two electrons that are in the excited singlet-state, The net spin of all the electrons in the system is... 0

26. [2pts] For a two-level system with two electrons that are in the excited triplet-state, The net spin of all the electrons in the system is... +1 or -1. Either answer is fine

27. [2pts] The Pauli exclusion principle necessitates that a filled orbital will have a net 0 spin with a maximum of how many of electrons **2**

28. [2pts] Nickel is a metal which is attracted by....

- a. None of the magnetic poles of magnet
- b. **Both magnetic poles of magnet**
- c. North pole of magnet
- d. South pole of magnet

29. [4pts] An electron has a magnetic dipole due to its spin. What is spin?

**Spin is the intrinsic angular momentum of the electron**

**+4 for similar answer**

30. [4pts] Why does the carbon-13 isotope respond to an external magnetic field while the carbon-12 isotope does not.

**The nuclear spin of carbon -12 is 0, so it does not respond to magnetic field. Carbon -13 has a spin of  $\frac{1}{2}$  so in the presence of a magnetic field it will either be in state spin  $\frac{1}{2}$  or  $-\frac{1}{2}$**

**+2 points talking about carbon-12**

**+2 points talking about carbon-13**

## **Quantum Information Processing**

31. The math governing Quantum Information Processing is different than Binary logic.

- a. [4pts] In creating a programming structure, language, compiler, etc for quantum computers, Boolean Algebra is not practical due to what limitation of quantum superposition?

All operations must be reversible

+4 for similar answer

- b. [4 pts] What operations in standard digital machine level architecture cannot be used in Quantum state level architecture?

NAND, EXOR functions can't be used

+2 points for NAND

+2 points for EXOR

- c. [4 pts] What operators allow a quantum state level machine to be used?

The Hadamard transform and the CNOT gate allows for logic and entanglement of Quantum Storage sites

+2 points for Hadamard

+2 points for CNOT

32. [2pts] Recently, a new 8 Qubit component chip was announced. The documentation indicates that it uses Majorana sites in a topological superconductor. The Majorana fermion was first proposed in 1934 but has never been observed. What unique property does this potential particle have?

a. It is massless

b. It is its own antiparticle

c. It has a charge of  $-1/2$

d. All the above

33. [2 pts] The claimed superiority of this topological superconductor Qubit design is...

a. The speed at which superposition can be established and read

b. The high tolerance to noise due to the Majorana robustness

c. Long stability of the Qubit state

d. All the above

34. [2pts] Bell's theorem disproves realism

a. True

b. False

35. [2pts] How many qubits are involved in Shor's code for quantum error correction? 9

36. An extensively researched quantum storage mechanism is N-V centers in diamond.

a. [2pts] What element does N refer to in this quantum storage mechanism?

a. Nitrogen

b. Neon

c. Nickel

d. Niobium

e. Neptunium

f. Neodymium

b. [2pts] One charge state of the N-V center is  $NV^0$ .  $NV^0$  is paramagnetic which means it is weakly repelled by an external magnetic field

a. True

b. False

c. [2pts]  $NV^-$  center can be thought of as a qubit with  $m_s = 0$  and  $m_s = \pm 1$  states. What type of radiation is shone at the NV center to change the state?

a. X-rays

b. Ultraviolet

c. Visible Light

d. Infrared

e. Microwaves

f. Radio waves

d. [2pts] What type of radiation is used to measure the state of the NV center?

a. X-rays

b. Ultraviolet

c. Visible Light

d. Infrared

e. Microwaves

f. Radio waves