

1

- i) 4
  - 14:05
- ii) 4
  - $1.0 \times 10^4$ , note seconds to minutes conversion in addition to pico-nano)
- iii) 2
  - 27,000,000 meters using  $E = hc/\lambda$
- iv) 2
  - 1972-01-01 or January 1, 1972
- v) 3
  - 536,112,000
- vi) 0
  - March 20, 1989 at 15:27
- vii) 2
  - 12 notes will be heard because the next time the clock sounds will be 11:45 and the following tune plays at every  $\frac{3}{4}$ -hour mark:
- viii) 2
  - 20, because the complete leap year in the Hebrew calendar has 385 days. Most years have only 354, however.
- ix) 2
  - $2.22028 \times 10^{-19}$  J, found using  $h\nu = |E_1 - E_2|$
- x) 8
  - 8, no conversion necessary as the number of nodes on a standing wave does not depend on its amplitude

2

- i. T
  - This is due to a mistake that the priests keeping the calendar made, and was not on purpose. Several years after the mistake was caught around 9 BC required corrections to get back to the typical leap year every 4 years.
- ii. T
  - Every 97 years out of 400 are leap years.
- iii. F
  - It's actually based on the Earth's rate of rotation around the Sun.
- iv. T

- This is the definition of the “equation of time”.

v. T

- The period is given by  $1/f$  where  $f = \omega/(2\pi)$  and  $\omega = \sqrt{k/m}$ . Plugging in the values given results in 3.44s.

vi. F

- It was 1908, not 1911!

vii. F

- The swing speed will decrease as the metal rod lengthens due to the increased temperature.

viii. T

- One of the biggest issues quartz clocks have with accuracy is the change in resonant frequency with temperature.

ix. T

- Azeptosecond is a trillionth of a billionth of a second. It has been measured that the time it takes for a light particle to cross a hydrogen molecule is 247 zeptoseconds.

x. T

- This can be rationalized by thinking about how the gas in the bottom bulb has to diffuse through the sand into the top bulb in order to equalize pressure, otherwise a vacuum would be created in the top bulb as the sand leaves.

3

i) A

- The last month of the Islamic calendar, Dhu al-Hijjah, is the one which is lengthened during the 11-year leap year cycle.

ii) B

- All others rely on the definition of a second

iii) D

- A and B are both correct, however the signal produced is not exactly 1 Hz. The signal is actually significantly higher, and control circuitry lowers it to the appropriate 1 Hz. A 1 Hz resonator would not be practical, and so it not used.

iv) C

- A mainspring, the part that is wound in a wind-up watch, does not apply equal torque at all points in its winding, meaning the clock could run too fast or too slow. Therefore a better mainspring applies more equal torque for a longer period of time. Mainsprings can not be overwound, and they do not have teeth

to mesh with gears. Instead, a post that runs through the center of the wound-up spring has teeth to mesh with gears.

v) C

- This is the definition of an envelope.

vi) C

- A has incorrect amplitude, period of B is too large, period of D is too small, E uses a cosine instead of a sine fit among other incorrect parameters. The correct answer can be determined easily by checking a few relevant points and parameters.

**The following bolded answers are questions to be used as tie breakers in the event of a tie.**

vii) **D**

- day of week for any date can be determined using Doomsday algorithm

viii) **B**

- the Paleozoic era is the first of three eras that the Phanerozoic eon is divided into

ix) C

- this is true for the cesium clock, not hydrogen

x) **D**

- a calendar from year X, the third year after a leap year, can be used in the years X+11, X+22, X+28. 2048 does not fit these criteria if X is 2019 and is the only incorrect year provided

4

**Award one point per correct answer chosen up to a maximum of 3.**

**Special case: if a student chooses any incorrect answers, subtract 1 point for the first incorrect choice.**

**Subtract an additional 1 point if all answers are selected.**

**Example: If A, B, C, and D are correct and they pick A, B, C, E □ 2 points**

*If they pick A, B, C, D, and E □ 1 point*

*If they pick A, B, and C OR A, B, C, and D □ 3 points*

*If they pick A and B only □ 2 points. If they pick A only □ 1 point.*

i)     Correct: A, B, E  
          Incorrect: C, D

- the position of the gnomon is relevant to the hemisphere of the Earth and the shape of the shadow does not matter

ii) Correct: B, D, E  
Incorrect: A, C

- A is true for Barycentric Dynamical Time (TDB) not TCB, C is true for the former standard astronomical time scale Ephemeris Time (ET), which is no longer in use

iii) Correct: A, C, D  
Incorrect: B, E

- All of the options except B are true. There are no references to pyramids being used to measure time and they would not make very good sundials. E is incorrect (although a true fact) because a clepsydra is a water clock, not an astronomical clock.

iv) Correct: C, D, E  
Incorrect: A, B

- In A and B, the gnomon's shadow will move at different speeds at different times of day, thus the lines can't be evenly spaced.

v) Correct: A, B, C, E  
Incorrect: D

- Once the water is in the collection tank, it no longer has any relevance to the clock. Hard water buildup on the outlet hose, as well as high water viscosity, can both slow the rate of flow through this tube. When the pressure in the reservoir is low, the flow of water will also be slower. Since the time is read by a camera, very thick lines can cause significant estimation error, if the camera has to decide for example between two nearby lines at 12:01 and 12:02.