Physics 221, Fall 2009
Quiz 6, Form: A

Name: Key

Date:

$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s

1 eV $= 1.6 \times 10^{-19}$ J

Region	**Wavelength**	**Frequency**	**Energy**
Gamma Rays	< 0.001 nm	$> 10^{20}$ Hz	> 1 MeV
X-rays	10 nm – 0.001 nm	$3 \times 10^{16} - 1 \times 10^{20}$ Hz	124 eV – 1 MeV
Ultraviolet	400 nm – 10 nm	$7.5 \times 10^{14} - 3 \times 10^{16}$	3.1–124 eV
Visible	750 nm – 400 nm	$4 \times 10^{14} - 7.5 \times 10^{14}$ Hz	1.65 – 3.1 eV
Infared	1 mm – 750 nm	$0.003 \times 10^{14} - 4 \times 10^{14}$	0.0012 – 1.65 eV
Millimeter Waves, Telemetry	10 mm – 1 mm	30 – 300 GHz	$1.2 \times 10^{-4} - 1.2 \times 10^{-3}$ eV
Microwaves, Radar	187 mm – 10 mm	1.6 – 30 GHz	$6.6 \times 10^{-6} - 1.2 \times 10^{-3}$ eV
TV and FM Radio	5.55 m – 0.187 m	54 – 1600 MHz	$2.2 \times 10^{-7} - 6.6 \times 10^{-5}$ eV
Short Wave	187 m – 5.55 m	1.605 – 54 MHz	$6.6 \times 10^{-9} - 2.2 \times 10^{-7}$ eV
AM Radio	600 m – 200 m	500 – 1500 kHz	$2 \times 10^{-9} - 6.6 \times 10^{-9}$ eV

Table 1: Electromagnetic Spectrum

Region	**Wavelength**	**Frequency**	**Energy**
Violet	440 nm – 400 nm	$6.8 \times 10^{14} - 7.5 \times 10^{14}$ Hz	2.8 – 3.1 eV
Blue	480 nm – 440 nm	$6.3 \times 10^{14} - 6.8 \times 10^{14}$ Hz	2.6 – 2.8 eV
Green	560 nm – 480 nm	$5.4 \times 10^{14} - 6.3 \times 10^{14}$ Hz	2.2 – 2.6 eV
Yellow	590 nm – 560 nm	$5.1 \times 10^{14} - 5.4 \times 10^{14}$ Hz	2.1 – 2.2 eV
Orange	630 nm – 590 nm	$4.8 \times 10^{14} - 5.1 \times 10^{14}$ Hz	2.0 – 2.1 eV
Red	700 nm – 630 nm	$4.3 \times 10^{14} - 4.8 \times 10^{14}$ Hz	1.8 – 2.0 eV

Table 2: Visible Region of the Electromagnetic Spectrum

Section 1. Multiple Choice

Questions 1–3 pertain to the following situation. A styrofoam cup contains 250 ml of water at 100 °C. You observe that after 30 minutes, the temperature is 25 °C. Define the water as the system. The specific heat capacity of water is 4190 J/kg/°C and its density is 1 g/ml. Assume that no mass of water is lost due to evaporation.

1. What is the change in the thermal energy of the system? (Be sure to get the sign correct.)

   (a) -1.05×10^5 J
   (b) -2.62×10^4 J
   (c) 2.62×10^4 J
   (d) -7.86×10^4 J
   (e) 7.86×10^4 J

   $\Delta E = mc\Delta T$
   $= (0.25\,kg)(4190)(25-100)$
   $= -7.86\times 10^4$ J
   It cooled, so ΔE is $-$.

2. What is the change in the energy of the surroundings? (Be sure to get the sign correct.)

   (a) -1.05×10^5 J
   (b) -2.62×10^4 J
   (c) 2.62×10^4 J
   (d) -7.86×10^4 J
   (e) 7.86×10^4 J

   $\Delta E_{surr} = -\Delta E_{sys}$
   $= 7.86\times 10^4$ J
   Cons. of E!

3. What is the change in temperature of the surroundings?

   (a) It cannot be determined from the given information.
   (b) 75°C
   (c) −75°C
   (d) 25°C
   (e) 100°C

   $\Delta E_{surr} = mc\Delta T_{surr}$
   ? ? ?
   And it's not homogeneous material either.

4. 1000 J of thermal energy is transferred to 1 kg of water which has a specific heat of 4190 J/kg/°C. The same amount of energy is transferred to 1 kg of antifreeze (ethylene glycol) which has a specific heat of 2510 J/kg/°C. Which one's temperature will increase the most?

   (a) the water $4190 \frac{J}{kg^\circ C}$
   (b) the antifreeze $2510 \frac{J}{kg^\circ C}$
   (c) neither, their temperatures will increase by the same amount.

   $\Delta E = mc\Delta T$ $\quad \Delta T \propto \frac{1}{c}$
   $\Delta T = \frac{\Delta E}{mc}$ $\quad$ less c, greater ΔT

5. 1500 J is transferred to a system as a result of a temperature difference between the system and its surroundings. During the same time interval, the change in the energy of the system is 1000 J. What is the work done on the system during this time interval?

   (a) -500 J
   (b) 500 J
   (c) -2500 J
   (d) 2500 J
   (e) zero

   $\Delta E = W + Q$
   $W = \Delta E - Q$
   $= 1000\,J - 1500\,J$
   $= -500\,J$

6. The amount of energy transferred to or from a system as a result of a temperature difference between the system and its surroundings is called

   (a) work
   (b) mechanical energy
   (c) thermal energy
   (d) heat
   (e) total energy

7. In class, a video of a ball-and-spring model of a solid was shown. The balls, representing atoms, were in a lattice and were oscillating. At any instant, one can calculate the sum of the spring potential energies of all bonds (springs) and the kinetic energy of all atoms (balls). The sum of the potential energy of all bonds and kinetic energy of all atoms in the solid is the solid's

   (a) heat
   (b) particle energy
   (c) thermal energy
   (d) rest energy
   (e) work

8. In one pot, you have 1.0 kg of water at a temperature of 5°C and in another pot you have 1.0 kg of water at a temperature of 30°C. Which pot of water requires more energy to raise its temperature to a final temperature of 50°C?

   bigger ΔT, bigger ΔE
   since $\Delta E = mc\Delta T$

   (a) the water at 5°C
   (b) the water at 30°C
   (c) Neither, both will require the same energy to raise its temperature to a final temperature of 50°C

9. Which has more thermal energy, 0.1 kg of liquid water at 100°C or 0.1 kg of gaseous water (i.e. steam) at 100°C?

    (a) liquid water

    (b) gaseous water (steam)

    (c) neither, because they have the same thermal energy.

You have to break bonds between molecules in order to evaporate the liquid.

10. Three students give their reasoning for the three choices in the previous question:

    Student 1: "Given that they have the same mass and temperature, liquid water has more thermal energy than steam because when molecules are bound in a liquid, they have both potential energy and kinetic energy. When molecules are a gas, they only have kinetic energy. As a result, liquid water has a greater thermal energy than steam."

    Student 2: "Given that they have the same mass and temperature, steam has more thermal energy than liquid water because some of the liquid water molecules are bound to each other. When they become unbound (by evaporating and becoming a gas), the molecules have more kinetic energy and less potential energy, so they have more total energy. As a result, steam has a greater thermal energy than liquid water."

    Student 3: "Given that they have the same mass and temperature, liquid water and gaseous water (steam) have the same thermal energy because thermal energy depends on temperature. Since the liquid water and steam have the same temperature, then they have the same total energy."

    Which student's reasoning is physically correct?

    (a) Student 1

    (b) Student 2 $\longrightarrow$ A$^+$ answer!

    (c) Student 3

11. Hydrogen is in its *second* excited state. What is its energy level, n? Warning: this can be tricky.

    — 3 2nd excited state

    — 2

    — 1 ground state

    (a) 1

    (b) 2

    (c) 3

    (d) 4

    (e) 5

12. A hydrogen atom is in the state $n = 2$. Monochromatic light of energy 1.0 eV shines on the atom. If it absorbs a photon, what state will it be in?

    $E_2 = \frac{-13.6\,eV}{2^2} = -3.4\,eV$

    $E_3 = \frac{-13.6\,eV}{3^2} = -1.51\,eV$

    min. E needed to absorb photons

    $|E_3 - E_2| = 1.87\,eV$

    (a) 1

    (b) 3

    (c) 4

    (d) 5

    (e) It will remain in the state $n = 2$ because hydrogen in this state will not absorb a photon of energy 1.0 eV.

13. For the previous question, suppose that monochromatic light of energy 2.86 eV shines on the atom. If it absorbs a photon, what state will it be in?

    $E_4 = 0.85$

    $E_5 = 0.544\,eV$

    $|E_5 - E_2| = 2.86\,eV = E_{photon}$

    (a) 1

    (b) 3

    (c) 4

    (d) 5

    (e) It will remain in the state $n = 2$ because hydrogen in this state will not absorb a photon of energy 2.86 eV.

14. What is the minimum energy required to ionize a hydrogen atom that is in the state n=2? (To ionize the atom means that the electron escapes the proton and becomes unbound.)

    $E_2 = -3.4\,eV$

    $E = 0$ is needed to escape.

    (a) 1.51 eV

    (b) 3.4 eV

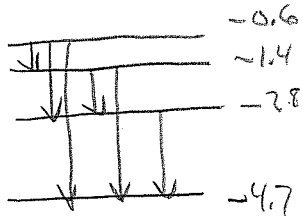
    (c) 10.2 eV

    (d) 12.09 eV

    (e) 13.6 eV

Questions 15–17: A hypothetical atom has the following energy states and can initially be in any of the states.

-0.6 eV (third excited state)
-1.4 eV (second excited state)
-2.8 eV (first excited state)
-4.7 eV (ground state)



15. What is the highest energy photon that it can emit?

    (a) 2.2 eV
    (b) 5.3 eV
    (c) 7.5 eV
    (d) 4.1 eV
    (e) 4.7 eV

    $4.7 - 2.8 = 1.9\ eV$
    $4.7 - 1.4 = 3.3\ eV$
    $4.7 - 0.6 = 4.1\ eV$
    $2.8 - 1.4 = 1.4\ eV$
    $2.8 - 0.6 = 2.2\ eV$
    $1.4 - 0.6 = 0.8\ eV$

16. How many different emission lines would occur in the spectrum for a gas of these atoms?

    (a) 9
    (b) 2
    (c) 4
    (d) 3
    (e) 6

    6 transitions possible

17. How many of the emission lines would be in the visible region? (1.8 eV – 3.1 eV)

    (a) 1
    (b) 2
    (c) 3
    (d) 4
    (e) none are in the visible region

    1.9 eV and 2.2 eV are in the visible region

18. If a hydrogen atom transitions from the n=2 state to the n=1 state, what kind of photon is emitted?

    (a) x-ray
    (b) UV
    (c) visible
    (d) radio
    (e) IR

    $E_2 = -3.4\ eV$
    $E_1 = -13.6\ eV$
    $|\Delta E| = 10.2\ eV$

    U.V., see table

19. An electron collides with a hydrogen atom that is in its ground state. If the kinetic energy of the electron is 11.0 eV just before it collides with the hydrogen atom, how much kinetic energy would the electron have after the collision if it excites the hydrogen atom into a higher energy state?

    e^- v_i H

    (a) 0.8 eV
    (b) 10.2 eV
    (c) 2.6 eV
    (d) 7.6 eV
    (e) zero

    $\Delta E_{e^-} + \Delta E_H = 0$
    $\Delta K_{e^-} = -\Delta E_H$
    $= -(E_2 - E_1)$
    $= -(10.2\,eV) = -1$
    $K_f = K_i + \Delta K = 0.8\,eV$

20. An NO molecule (nitrogen monoxide or nitric oxide) can be modeled as a harmonic oscillator. If the molecule gains energy, its frequency of oscillation

    (a) increases
    (b) decreases
    (c) remains the same

    E does not depend on ω

21. For the NO molecule in the previous question, if the molecule gains energy, the amplitude of its oscillation

    (a) increases
    (b) decreases
    (c) remains the same

    $E = \frac{1}{2} k A^2$

Note: $x = \frac{1}{2}A$, so $U = \frac{1}{4}E$ so $K = \frac{3}{4}E$
and $v = \sqrt{\frac{3}{4}}\, v_{max} = \sqrt{\frac{3}{4}}\,(0.12 \frac{m}{s}) \approx 0.1$

Questions 22–24: A simple harmonic oscillator consists of a mass of 0.1 kg on a vertical spring of stiffness 15 N/m. It oscillates about equilibrium with an amplitude of 0.01 m.

22. What is the total energy of the oscillator?

(a) 5.0×10^{-6} J
(b) 5.0×10^{-4} J
(c) 7.5×10^{-4} J
(d) 0.98 J
(e) 0.098 J

$E = \frac{1}{2}kA^2$
$= \frac{1}{2}(15)(0.01)^2$
$= 7.5 \times 10^{-4}$ J

23. What is the speed of the object when it passes through the equilibrium point?

(a) 1.95 m/s
(b) 0.51 m/s
(c) 0.26 m/s
(d) 0.12 m/s
(e) 0.06 m/s

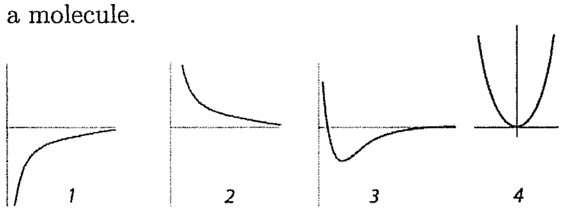
$K_{max} = E$
$\frac{1}{2}mv_{max}^2 = E$
$v_{max} = 0.122 \frac{m}{s}$

24. When the spring is stretched 0.005 m, what is its speed?

(a) 0.061 m/s
(b) 0.25 m/s
(c) 0.033 ms/
(d) 0.085 m/s
(e) 0.10 m/s

$E_i = E_f$
$U_f + K_f = 7.5 \times 10^{-4}$ J
$K_f = 7.5 \times 10^{-4} - \frac{1}{2}k(0.005)^2$
$= 7.5 \times 10^{-4} - 1.88 \times 10^{-4}$ J
$v = \sqrt{\frac{2K}{m}} = \boxed{0.11 \frac{m}{s}}$

25. Which of the graphs below shows the potential energy of two neutral atoms bound together in a molecule.



(a) 1
(b) 2
(c) 3
(d) 4
(e) None of the above

Section 2. Problem Solving

26. A child's pogostick consists of a stiff spring at the bottom of the stick. You use video analysis to study a child jumping up and down on the pogostick. At his lowest point, when the spring is maximally compressed, the spring is compressed 0.05 m. When the child is at his peak, he is ~~0.4~~ 0.3 m m above his lowest point. The mass of the child and pogostick together is 35 kg. A simplified model of the situation is shown below, where the child and pogostick are treated as a single particle.

System = kid, spring, Earth.

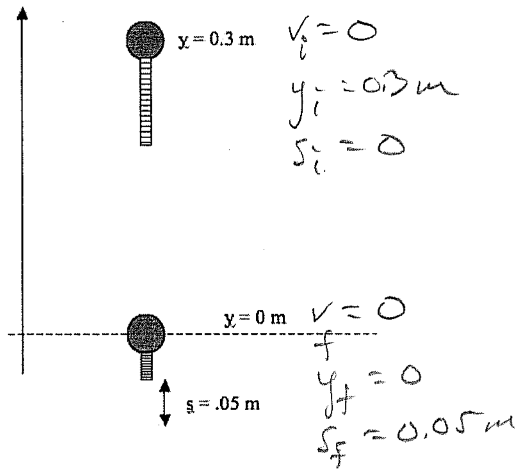


Figure 1: A model of a child on a pogostick.

(a) What is the potential energy of the spring at the child's lowest point? (Note: use conservation of energy.)

$$E_i = E_f$$

$$U_{grav\,i} + \cancel{K_i}^{0} + \cancel{U_{spring\,i}}^{0} = \cancel{U_{grav\,f}}^{0} + \cancel{K_f}^{0} + U_{spring\,f}$$

$$mgy_i = U_{spring\,f}$$

$$mgy_i = \tfrac{1}{2} k s_f^2$$

$$U_{spring\,f} = mgy_i = (35\,kg)(9.8\,\tfrac{N}{kg})(0.3\,m) = \boxed{103\,J}$$

(b) What is the stiffness of the spring?

$$U_{spring\,f} = \tfrac{1}{2} k s_f^2 = 103\,J$$

$$k = \frac{2\,(103\,J)}{(0.05)^2}$$

$$= \boxed{8.23 \times 10^4\ \tfrac{N}{m}}$$

27. 0.5 kg of water at 100°C is poured into a 0.25-kg glass mug (c_{glass} = 840 J/kg/K) at 20°C.

(a) What will be the equilibrium temperature of the system if the system is thermally insulated from its surroundings?

$\Delta E_{sys} = 0$ System = water + mug

$\Delta E_{water} + \Delta E_{mug} = 0$

$m_w c_w \Delta T_w + m_{mug} c_{mug} \Delta T_{mug} = 0$

$(0.5\,kg)(4190\,\frac{J}{kg\,°C})(T_f - 100) + (0.25\,kg)(840\,\frac{J}{kg\,°C})(T_f - 20) = 0$

$T_f = 92.7°C$

$\boxed{T_f \approx 93°C}$

(b) What is the change in thermal energy of the ~~coffee~~ water?

$\Delta E_{water} = m_w c_w \Delta T_w$

$= (0.5\,kg)(4190\,\frac{J}{kg\,°C})(92.7 - 100) = \boxed{-1.5 \times 10^4\,J}$

(c) What is the change in thermal energy of the mug?

$\Delta E_{mug} = m_{mug} c_{mug} \Delta T_{mug}$

$= (0.25\,kg)(840\,\frac{J}{kg\,°C})(92.7 - 20)$

$= \boxed{1.5 \times 10^4\,J}$

Note: $\Delta E_{mug} = -\Delta E_{water}$ as expected.

It is an isolated (insulated, closed) system, so

$\Delta E_{sys} = 0$.

This is a good way to check your work.

28. (a) An acrobatic ski jumper in the X-Games uses the jump shown below. She starts from rest at an elevation of 50 m above the base of the ramp. The height of the ramp above its base is 8 m. What is the speed of jumper at the top of the ~~jump~~ ramp. if the snow is frictionless? The skier's mass, including skis, is 70 kg.

System ≡ Skier + Earth.

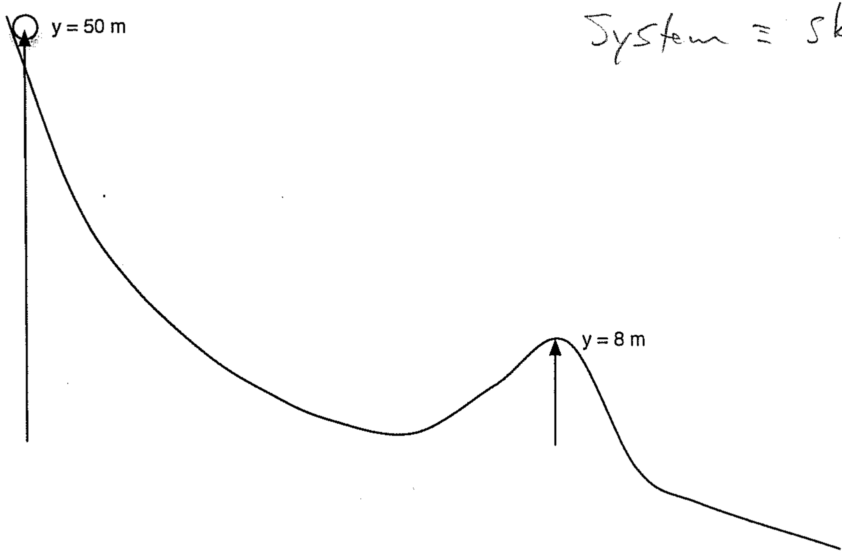


Figure 2: A ski jump.

$E_i = E_f$ for a closed system. (no work).

$U_i + \cancel{K_i}^{0} = U_f + K_f$

$\cancel{m}gy_i + 0 = \cancel{m}gy_f + \frac{1}{2}\cancel{m}v_f^2$

$v_f = \sqrt{2g(y_i - y_f)} = \sqrt{2(9.8)(50-8)} = \boxed{29\ \frac{m}{s}}$

(b) Snow is not frictionless. Thus, her actual speed is less than the speed calculated in part (a). Suppose that using video analysis, you calculate her speed at the top of her jump to be 15 m/s? What is the change in thermal energy of the skier, snow, and air as a result of friction and air resistance?

System ≡ skier, Earth, snow, and air.

$\Delta E_{sys} = 0$

$\Delta U_{grav} + \Delta K + \Delta E_{therm} = 0$

$\Delta E_{therm} = -\Delta U + -\Delta K$

$= -(U_f - U_i) - (K_f - \cancel{K_i}^{0})$

$= mg(y_i - y_f) - \frac{1}{2}mv_f^2 = (70\,kg)(9.8\,\frac{N}{kg})(50-8) - \frac{1}{2}(70)(15)^2$

$= 2.88 \times 10^4\,J - 7.875 \times 10^3\,J$

$= \boxed{2.1 \times 10^4\,J}$

Note: thermal energy increased, as expected due to friction.

Section 3. Lab

29. A graph of spring potential energy and total energy as a function of distance stretched from equilibrium for a harmonic oscillator is shown below. $x = 0$ is defined to be a the position of the object when the spring is unstretched. The mass of the object is 0.1 kg.

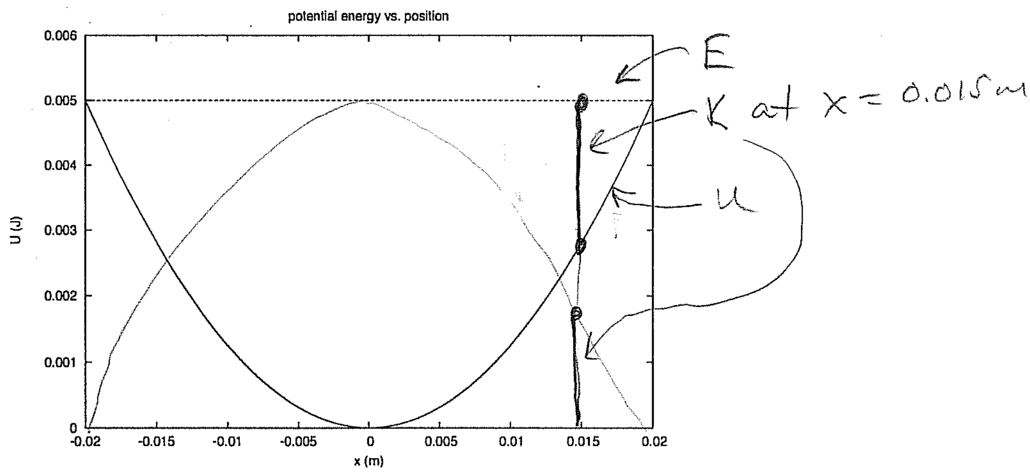


Figure 3: U, E vs. x for a harmonic oscillator.

(a) On the above set of axes, sketch a graph of K vs. x for the harmonic oscillator.

(b) What is the amplitude? $\boxed{A = 0.02\ m}$, where $E = U$.

(c) What is the total energy? $\boxed{E = 0.005\ J}$ (see horizontal line

(d) What is the stiffness of the spring? $E = \frac{1}{2}kA^2$, so $\boxed{k = 25\ \frac{N}{m}}$

(e) When the object is at $x = 0.015$ m, what is the kinetic energy of the system, as determined from the graph? Describe how you obtain this from the graph? Your answer may be approximate since you will get it from the graph. $K = E - U$ they are the vertical lines drawn.

$K = 0.005 - 0.003 = \boxed{0.002\ J}$

(f) Determine the kinetic energy for the previous question algebraically and show that your answer to (e) is approximately correct. $U = \frac{1}{2}(25)(0.015)^2 = 0.0028\ J$

$K = 0.005\ J - 0.0028\ J = \boxed{0.0022\ J} \approx 0.0028\ J$

30. (a) The bright green emission line for Mercury from the fluorescent bulbs that you used to calibrate the hand-held spectrometer has a wavelength of 546 nm. What is the frequency of this line? (i.e. the frequency of the emitted photon) $546\ nm = 546 \times 10^{-9}\ m$

$f = \frac{c}{\lambda} = 5.49 \times 10^{14}\ Hz$, $E = hf = \boxed{2.27 eV}$

(b) What is the energy of the emitted photon in eV?

(c) Did the energy of the Mercury atom increase or decrease as a result of emitting the green photon?
For emission of photon, ΔE_{atom} is $-$, so E decreased.

(d) What physicist suggested that light is a particle and called it a photon and proposed that its energy is $E = hf$?

Einstein.