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CHEMISTRY
NOVEL-RESULT

Obtaining molecular hydrogen from water radiolysis in the nano-SiO_2($d = 20$ nm)/H_2O system under the influence of γ-quanta

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Abstract
Under the influence of γ-quanta (^{60}Co, $P = 9.276$ rad/s, $T = 300$ K), the amount, formation rate, and radiation-chemical yield of molecular hydrogen obtained from the radiolysis process that changes the mass of water ($m = 0.0001 \div 0.8$ g) have been defined in the created nano-SiO_2/H_2O system with $m = 0.2$ g mass and $d = 20$ nm particle size. It was determined that the radiation-chemical yield of molecular hydrogen obtained from the water radiolysis process in the nano-SiO_2/H_2O system created by the adsorption of water on the nanoparticle surface had a low value. In systems created with the addition of water, the radiation-chemical yield of molecular hydrogen obtained from its radiolysis increased in direct proportion to the water mass. This proves that due to ionizing rays, the yield of electrons emitted from the nanoparticle surface into the water and solvated there increases. Therefore, the radiation-chemical yield of molecular hydrogen is higher than that of the adsorbed system.

Keywords: electron emission; nanoparticle; radiation-chemical yield; radiolysis

Introduction

In recent inquiries conducted on the process of radiolysis by analysts around the world including us, the study of items obtained from the radiolysis handling of fluids, particularly water in contact with metal or metal oxides under the impact of ionizing beams (γ-quanta, electrons, protons, neutrons, α-particles, high-energy particles, etc.), is of extraordinary significance both logically and vivaciously. The dependence of the radiation-chemical abdicate of the items obtained from the tests on the molecule measure of metal or metal oxides (estimate impact), on their mass in suspended frameworks (mass impact), and on their sort was observed, and the impact was found to be more articulated in nanoscale metal or metal oxides. In summary, the radiation-chemical yield of nuclear hydrogen obtained from the radiolysis of water adsorbed on the surface of nano-ZrO_2 (LaVerne & Tandon, 2002; Le Caër, 2011) is higher than that of other metal oxides. On the other hand, the radiation-chemical surrender of atomic hydrogen obtained from radiolysis handling with ZrO_2 (Le Caër, 2011; Petrik et al., 2001) and silicate nanoparticles (LaVerne & Tonnies, 2003; Schatz et al., 1998) suspended in water is higher than that of adsorbed frameworks. It was proposed (Schatz et al., 1998) that the increment of atomic hydrogen obtained from the water radiolysis in suspended frameworks may be

related to the emanation of a portion of the electrons shaped interior the silicate from its surface to the fluid stage, that is, into the water. In the water radiolysis process on a nano-sized silicate surface, when the pore sizes are reduced, the radiation-chemical yield of OH decreases (Foley et al., 2005), whereas the yields of H_2 and H_2O_2 increase (Rotureau et al., 2005).

Ouerdane et al. (2010) calculated the radiation-chemical yields of the electron–hole (ion) pair shaped within the physical and physical–chemical stages of the method by the impact of ionizing beams on the undefined nano-SiO_2 framework suspended in water utilizing the Monte Carlo strategy. Later, their migration trajectories were followed. Based on the model, the migration of holes formed inside SiO_2 to the surface was monitored. Also, the relocation of the electrons shaped interior the nanoparticle to the surface and the radiation-chemical abdicate of, to begin with, warm, at that point solvated electrons radiated from the surface into the water have been calculated. It has been chosen that the radiation-chemical yield of electrons transmitted from the surface of nano-SiO_2 into water and solvated their shifts depending on the degree and porosity of the nanoparticle (Ouerdane et al., 2010). These comes about are in understanding with exploratory comes about (Dimitrijevic et al., 1999). The electron emission from the oxide surface into water under the influence of ionizing rays on various nano-sized oxide (SiO_2, ZnO, Al_2O_3, Nd_2O_3, Sm_2O_3, and Er_2O_3) systems suspended in water (Chelnokov et al., 2014) was determined. The comparison of the spectra of electrons solvated in those systems and in pure water proves that in the picosecond–nanosecond range, it is the same in both systems in water, and in the nanosecond–microsecond range, it is higher in the metal oxide/water system than in pure water.

The production of molecular hydrogen from water decomposition under the influence of γ-quanta and 5 MeV energy He ions on the SiC (α-phase and β-phase) nanoparticle/water system was studied by Schofield et al. (2016). Their research work was carried out in two ways: (a) water adsorption and (b) suspension of SiC in water. Spectroscopic analyses proved that the α-phase changes to the β-phase under the influence of radiation and the oxidation of silicon on the SiC surface occurs, that is, SiO_2 is obtained, and the radiation-chemical yield of molecular hydrogen in the suspended system is higher than that in the adsorbed system.

The time-dependent yield of electrons solvated during the influence of γ-quanta with a 20 s pulse on the suspension of glass nanoparticles with different porosity (1–57 nm) has been considered by Musat et al. (2012), who determined that the energy yield of electrons solvated within 1 nm particle pores is two times higher than that of pure water. This proves that a part of the electrons formed inside a solid due to radiation is emitted from the surface of a solid to the liquid phase.

The radiation-chemical abdicate of atomic hydrogen obtained from the method of radiolysis of water adsorbed on the ZnO surface (Jafarov, 2022) under the impact of γ-quanta is much higher than that of unadulterated water. The authors explained this increase as a transferring of the energy absorbed by the oxide to the adsorbed water.

The products obtained during the radiolysis process of water adsorbed on the surface of ZrO_2 nanoparticles with accelerated electrons, γ-quanta, and 5 MeV doubly ionized helium ions (Roth et al., 2012) were studied using various spectroscopic methods. The maximum yield of molecular hydrogen was observed at values of the surface filling degree less than 1.

The production of molecular hydrogen from the water radiolysis process was studied in zeolite/water systems under irradiation by Kumagai et al. (2017). Four types of zeolites were used in the experiments. Zeolites with a high amount of aluminum are more catalytically active.

The abdicate of atomic hydrogen obtained from water deterioration amid the radiation-catalytic handle within the AL_2O_3/H_2O framework (Reiff & LaVerne, 2017) was considered under the impact of γ-quanta and helium particles with 5 MeV vitality. The radiation-chemical abdicate of atomic hydrogen decided by adsorbed water was $G(H_2) = 80 \pm 20$ molecule/100 eV.

Under the influence of γ-quanta, the radiation-chemical yields of molecular hydrogen obtained from the water radiolysis process (Jafarov, 2022), which changes the mass of water $m_{H_2O} = 0.01 \div 0.8$ g in nano-SiO_2/H_2O systems with a mass of $m = 0.2$ g and a particle size of $d = 20 \div 60$ nm, were studied. It was determined that with an increase in the water mass, the radiation-chemical yield of molecular hydrogen: decreases, $G(H_2) = 7.5$–0.74 molecule/100 eV, if determined for water; increases, $G(H_2) = 0.38$–2.98

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molecule/100 eV, if determined for nano-silica; increases, $G(H_2) = 0.36–0.98$ molecule/100 eV, at values of water mass 0.01 g $\leq m_{H_2O} <$ 0.2 g; reaches maximum, $G(H_2) = 1.1$ molecule/100 eV, at a value of water mass m_{H_2O}=0.2 g; and gradually decreases, $G(H_2) = 0.85–0.6$ molecule/100 eV, at a value of water mass 0.2 g $< m_{H_2O} \leq$ 0.2 g if determined for total system.

The radiation-chemical yield of molecular hydrogen obtained from water radiolysis in the systems created with the addition of silica with the particle size of $d = 50$, 100, and 300–500 nm and mass of $m = 0.01$, 0.02, 0.06, and 0.12 g suspended during irradiation (^{60}Co) in $V = 5$ ml of water were $G(H_2) = 10.9$, 8.07, and 5.24 molecule/100 eV, respectively. Both mass and size effects have been observed here. The authors explained that the yield is high due to the electrons emitted from the silica surface into the water.

The radiation-chemical yields of atomic hydrogen obtained from water radiolysis within the frameworks made with the expansion of BeO with the molecule estimate of $d < 4$, $d = 32–53$, and $d = 75–106$ μm and mass of $m = 0.01$, 0.02, 0.04, 0.08, and 0.2 g, suspended amid illumination in $V = 5$ ml water by the impact of γ-quanta were examined. From the obtained results, the radiation-chemical yields of molecular hydrogen were $G(H_2) = 2.79$, 2.29, and 1.66 molecule/100 eV if determined according to the total system, and $G(H_2) = 208$, 111, and 68.7 molecule/100 eV if determined according to BeO.

On the other hand, the abdicate of atomic hydrogen obtained from the radiation-thermo-catalytic deterioration (Jafarov et al., 2018b) under the impact of thermo-catalytic and γ-quanta that continue by changing the thickness of water within the BeO/H_2O made framework was examined. The inquire about work was carried out for BeO with molecule sizes $d < 4$ μm.

In summary, the water radiolysis process in suspended systems can be divided into three parts:

- homogeneous radiolysis of pure water;
- heterogeneous radiolysis of water in contact with a solid surface;
- water radiolysis processes under the influence of electrons emitted from the nanoparticle surface into water and solvated there.

Within the displayed work, under the impact of γ-quanta (^{60}Co, $P = 9.276$ rad/s, $T = 300$ K), the mass of water ($m = 0.001$ and 0.8 g), the sum, arrangement rate, and radiation-chemical yields of atomic hydrogen obtained from the radiolysis forms in nano-SiO_2/H_2O frameworks with a mass of $m = 0.2$ g and a molecule estimate of $d = 20$ nm were considered.

Experimental phase

High-purity (99.9%), "Skyspring Nanomaterials, Inc.," US-made amorphous nano-SiO_2 was used to study the amount, formation rate, and radiation-chemical yield of molecular hydrogen obtained from water radiolysis processes in the created nano-SiO_2/H_2O systems with a particle size of $d = 20$ nm under the influence of γ-quanta. Nano-SiO_2 was cooled after heat treatment in the open air at a temperature $T = 773$ K for $t = 72$ hr, then the necessary mass ($m = 0.2$ g) was added to the ampoule ($V = 9$ ml), cleaned, and thermally treated ($T = 773$ K) under special conditions. Nano-SiO_2 inside the ampoule was thermally treated ($T = 673$ K) for 4 hr under vacuum conditions ($P = 10^{-3}$ mmc.st.) and then cooled and sealed by expelling the required amount of bidistilled water purified from air under special conditions (Pikaev, 1975).

The ampoule was irradiated in a ^{60}Co source with a dose rate of $P = 9.276$ rad/s at room temperature. Absorbed dose strength was determined using ferrous sulfate and methane methods. In a specific research object, the strength of the absorption dose was calculated using electron density comparison methods (Jafarov et al., 1987; Pikaev, 1975).

It was analyzed that H_2, O_2, and H_2O_2 are the final molecular products obtained from the radiation-heterogeneous decomposition of water in the nano-SiO_2/H_2O created system. Since part of O_2 of these products is trapped on the catalyst surface and H_2O_2 is in solution, it creates great difficulties in determining their amounts. Therefore, more accurate information about the kinetic regularity of the products obtained from the radiation-heterogeneous decomposition processes of water was made based on the amount of molecular hydrogen.

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The amount of obtained molecular hydrogen was analyzed in an "Agilent-7890" chromatograph. To confirm the results, a modernized "Tsvet-102" chromatograph (accuracy 8–10%) was also used in parallel. A column with a length of 1 m and an inner diameter of 3 mm was used in the "Tsvet-102" chromatograph. Activated carbon with particle size $d = 0.25 \div 0.6$ mm was used inside the column, and argon gas with a purity of 99.99% was used as a gas carrier in both chromatographs.

Results and discussion

The reliance chart of the sum of atomic hydrogen obtained from the radiation-heterogeneous decay of water within the frameworks made by changing the mass of water ($m = 0.01$ (1), 0.02 (2), 0.04 (3), 0.08 (4), 0.2 (5), 0.4 (6), and 0.8 g (7)) included to nano-SiO_2 with the mass $m = 0.2$ g and molecule estimate $d = 20$ nm under the impact of γ-quanta (^{60}Co, $P = 9.276$ rad/s, $T = 300$ K) on the radiation time (dosage) is given in Figure 1.

From the linear parts of the kinetic curves (Curves 1–7 in Figure 1) obtained from the studied systems (nano-SiO_2/H_2O), the formation rates of molecular hydrogen (Jafarov, 2022) were determined for water, nano-silica, and the total system. The formation rate of molecular hydrogen obtained from the radiolysis of pure water was determined based on the following expression:

$$w_0(H_2) = 0{,}01 G_0(H_2) P \tag{1}$$

where $G_0(H_2) = 0.45$ molecule/(100 eV) is the radiation-chemical yield of molecular hydrogen obtained from the radiolysis of pure water, and P is the strength of the absorbed dose of the radiation source. From the kinetic part of the curves in Figure 1, the formation rate of molecular hydrogen was determined for water in the nano-SiO_2/H_2O system as

$$w_{H_2O}(H_2) = \frac{N(H_2)}{m_{H_2O} t} \tag{2}$$

for the total nano-SiO_2/H_2O system as

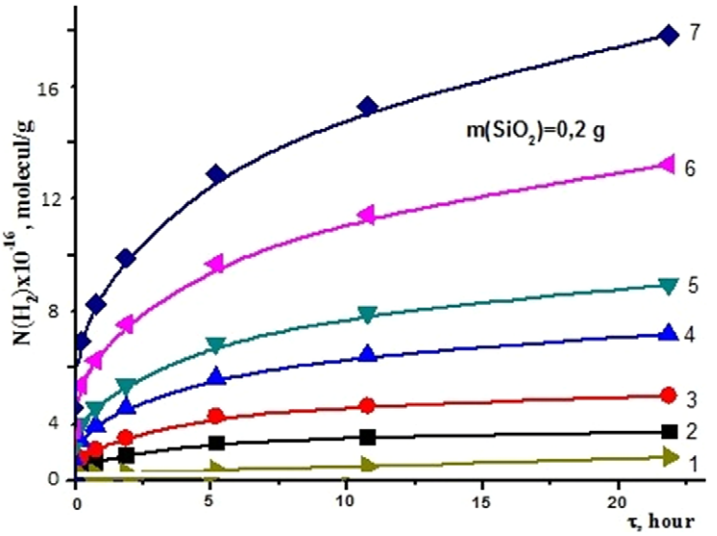

Figure 1. The dependence of the amount of molecular hydrogen obtained from the radiation-catalytic decomposition of water in the systems created by addition of water with the mass of $m = 0.01$ (1), 0.02 (2), 0.04 (3), 0.08 (4), 0.2 (5), 0.4 (6), and 0.8 g (7) to nano-SiO_2 with the mass $m = 0.2$ g and particle size $d = 20$ nm under the influence of γ-quanta (^{60}Co, $P = 9.276$ rad/s, $T = 300$ K) on the radiation time.

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Table 1. The formation rates of molecular hydrogen obtained from the radiation-catalytic decomposition of water in the systems created by the addition of water with the mass of $m = 0.001$, 0.003, 0.01, 0.02, 0.04, 0.08, 0.2, 0.4, and 0.8 g to the nano-SiO_2 with the mass of $m = 0.2$ g and the particle size of $d = 20$ nm under the influence of γ-quanta (^{60}Co, $P = 9.276$ rad/s, $T = 300$ K)

	m_{H_2O}, g								
$w(H_2)10^{-13}$, molecule/g·sec	0.001	0.003	0.01	0.02	0.04	0.08	0.2	0.4	0.8
$w_{SiO_2}(H_2)$	0.17	0.25	0.35	0.53	0.8	1.25	2.01	2.3	2.7
$w_{H_2O}(H_2)$	13.6	9.75	7.0	5.3	4.0	3.1	2.01	1.15	0.68
$w_{tot}(H_2)$	0.16	0.23	0.33	0.48	0.66	0.89	1.005	0.76	0.54

$$w_{tot}(H_2) = \frac{m_{H_2O}}{m_{H_2O} + m_{SiO_2}} w_{H_2O}(H_2) \tag{3}$$

and for nano-SiO_2 as

$$w_{SiO_2}(H_2) = \frac{m_{H_2O}}{m_{SiO_2}} [w_{H_2O}(H_2) - w_0(H_2)] \tag{4}$$

where the amount of molecular hydrogen obtained from the water radiolysis in the $N(H_2)$-nano-SiO_2/H_2O system is the mass of m_{H_2O}—water, m_{SiO_2}—nano-SiO_2, and$m_{tot} = m_{SiO_2} + m_{H_2O}$— the total system. In those systems, the formation rates of molecular hydrogen obtained from the water radiation-catalytic decomposition determined for the water (2), total system (3), and nano-SiO_2 (4) are given in Table 1.

Table 2 shows the dependence of the radiation-chemical yield of molecular hydrogen determined for the total system, water, and nano-SiO_2 on the water mass on the basis of those rates ($w_{tot}(H_2)$, $w_{H_2O}(H_2)$, and $w_{SiO_2}(H_2)$).

Figure 2 shows the graphs of the dependence of the radiation-chemical yield of molecular hydrogen on the water mass determined for the total system (curve 1), water (curve 2), and nano-SiO_2 (curve 3) based on those rates ($w_{tot}(H_2)$, $w_{H_2O}(H_2)$, and $w_{SiO_2}(H_2)$).

To explain the obtained results, let us establish a model. If we consider a nanoparticle as a sphere with radius R, then its volume can be determined based on the following expression:

$$V_{sph..} = \frac{4}{3}\pi R^3 \tag{5}$$

Table 2. The radiation-chemical yield of molecular hydrogen obtained from the radiation-catalytic decomposition of water in the systems created by the addition of water with the mass of $m = 0.001$, 0.003, 0.01, 0.02, 0.04, 0.08, 0.2, 0.4, and 0.8 g to the nano-SiO_2 with the mass of $m = 0.2$ g and the particle size of $d = 20$ nm under the influence of γ-quanta (^{60}Co, $P = 9.276$ rad/s, $T = 300$ K)

	m_{H_2O}, g								
$G(H_2)$, molecule/(100 eV)	0.001	0.003	0.01	0.02	0.04	0.08	0.2	0.4	0.8
$G_{SiO_2}(H_2)$	0.29	0.41	0.58	0.87	1.3	2.06	3.3	3.8	4.45
$G_{H_2O}(H_2)$	22.5	16.1	11.5	8.7	6.6	5.1	3.3	1.9	1.11
$G_{tot}(H_2)$	0.27	0.39	0.55	0.8	1.1	1.47	1.66	1.26	0.89

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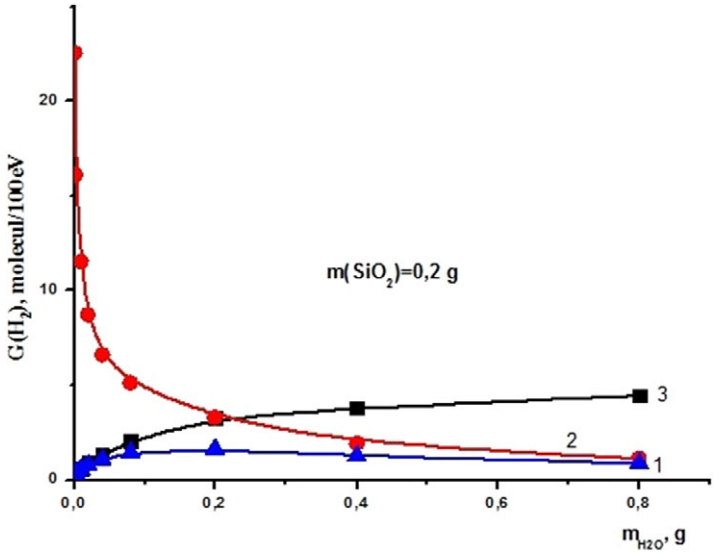

Figure 2. Dependence of the radiation-chemical yield of molecular hydrogen determined for the total system (curve 1), water (curve 2), and nano-SiO_2 (curve 3) obtained from radiation-catalytic decomposition of water in the created systems nano-SiO_2/H_2O with a mass of $m_{SiO_2} = 0.2$ g and a particle size of $d = 20$ nm under the influence of γ-quanta (^{60}Co, $P = 9.276$ rad/s, $T = 300$ K) on the water mass.

If the space between the nanoparticles is completely filled with water, then, if each particle is described as a cube with the edge $2R$ together with the corresponding water, the volume of water around the particle can be determined as follows:

$$V_{wat.} = V_{cub.} - V_{sph..} = (2R)^3 - \frac{4}{3}\pi R^3 = \left(8 - \frac{4}{3}\pi\right)R^3 \tag{6}$$

The mass of water can be defined as $m_{wat} = \rho_{wat.} \cdot V_{wat}$, and the mass of nanoparticle can be defined as $m_{sph.} = \rho_{sph.} \cdot V_{sph}$. Taking into account the data, the ratio of the mass of water to the mass of the catalyst can be calculated as follows:

$$\frac{m_{wat}}{m_{cat}} = \frac{\rho_{wat} \cdot V_{wat}}{\rho_{cat} \cdot V_{cat}} = \frac{\rho_{wat}}{\rho_{cat}} \frac{\left(8 - \frac{4}{3}\pi\right)R^3}{\frac{4}{3}\pi R^3} = \left(\frac{6}{\pi} - 1\right).\frac{\rho_{wat}}{\rho_{cat}} \tag{7}$$

Apparently, this ratio does not depend on the size of the nanoparticle. Considering the data $\rho_{SiO_2} = 2.33$ g/cm^3 and $\rho_{H_2O} = 1$ g/cm^3, this ratio is approximately 40%. That is, water added in excess creates a liquid phase on the surface. Therefore, the yield of molecular hydrogen gradually decreases (determined by the total system).

The obtained results can be explained on the basis of known mechanisms of radiation physics and chemistry. Due to the effect of γ-quanta, non-equilibrium energy carriers—electrons(e^-), holes $\left(SiO_2^+(h^+)\right)$, and electron-excitation states (SiO_2^*–excitons)—are formed inside the nanoparticle. This process can be symbolically described as follows:

$$SiO_2 \xrightarrow{\gamma} SiO_2^+(h^+), SiO_2^*, e^- \tag{8}$$

If the energy spent on the formation of an electron–hole pair in SiO_2 under the influence of ionizing rays (γ-quanta, electrons) is 19.1 eV (Aussman & McLean, 1975), then the radiation-chemical yield of the electron–hole pair is equal to $G(h^+–e^-) = 5.2$ pair/(100 eV). A part of the formed electron–hole pair can be recombined within the particle due to the Coulomb interaction (the Onsager effect). The other part of

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the holes migrates according to the drift mechanism (Levin et al., 2008): one part is captured by structural defects in the volume, and the other part is transported to the surface of the nanoparticle and captured by the adsorbed complex $[SiO_2 - H_2O_2]$ of water on the surface, forming the ion complex:

$$[SiO_2 - H_2O_s] + h^+ \rightarrow [SiO_2 - H_2O_s]^+ \tag{9}$$

By recombining that ion complex with thermal or tunneling electrons, they cause electron excitation of the complex:

$$[SiO_2 - H_2O_s]^+ + e^- \rightarrow [SiO_2 - H_2O]^* \tag{10}$$

On the other hand, the excitons generated by ionizing radiation can be absorbed inside the nanoparticle and transfer their energy to the water complex adsorbed on the surface. At this time, the electron excitation of the complex takes place:

$$exc + [SiO_2 - H_2O_s] \rightarrow [SiO_2 - H_2O]^* \tag{11}$$

The energy of the short-lived electron-excitation complex $(SiO_2\text{-}H_2O_s)^*$ (Alba-Simionesco, 2010) is transferred to the adsorbed water molecule, causing its decomposition, and as a result, H and OH intermediates are formed:

$$[SiO_2 - H_2O]^* \rightarrow SiO_2 - OH + H \tag{12}$$

In order to obtain intermediate products H and OH from the decomposition of a water molecule, it is necessary to break the bond between them ($E_{\text{bond}} = 5.1$ eV). Therefore, the energy of the transferred exciton (E_{exc}) and the bonding energy must satisfy the condition $E_{\text{exc}} \geq E_{\text{bond}}$.

On the other hand, the electrons molded inside the nanoparticle under the effect of radiation and each unused time of δ-electrons they make consistently lose their energetic imperativeness in adaptable and inelastic collisions inside the atom and, while some of them are captured by auxiliary forsakes inside the particle, some are transported to the surface of the atom. Among the electrons transported to the surface, a parcel of which engine essentialness is more diminutive than the surface potential is localized on the surface, and a parcel returns into the particle, while the greater ones are emanated into the water after crossing the surface of the particle. Electrons transmitted from the surface of a strong into water steadily lose their motor vitality in dipole unwinding, flexible and inelastic collisions, initially turn into warm electrons, and after that, they can be solvated (Liu et al., 1997):

$$e^- + nH_2O \rightarrow e^-_{aq} \tag{13}$$

It has been proved both experimentally (Dimitrijevic et al., 1999) and theoretically (Ouerdane et al., 2010) that the radiation-chemical yield of electrons solvated in the liquid phase (12) is higher in comparison with pure water in the created nano-SiO_2 systems suspended in water, and this value changes depending on the size of the nanoparticle.

We can describe the obtaining of molecular hydrogen from the radiolytic decomposition occurring between electrons solvated $\left(e^-_{aq}\right)$ in the interparticle liquid phase and water molecules as

$$2e^-_{aq} + 2H_2O \rightarrow H_2 + 2OH^- \tag{14}$$

atomic hydrogen:

$$e^-_{aq} + H + H_2O \rightarrow H_2 + OH^- \tag{15}$$

and protonated water molecules (H_3O^+):

$$e^-_{aq} + H_3O^+ \rightarrow H + H_2O \tag{16}$$

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Finally, molecular hydrogen can also be obtained in the following form:

$$H + H \rightarrow H_2 \tag{17}$$

From here, it is known that two electron–hole sets or two excitons are utilized to get one atomic hydrogen. Responses (8–12 and 17) basically play a part in getting atomic hydrogen from the radiation-heterogeneous deterioration of water adsorbed on the nano-SiO_2 surface under the impact of γ-quanta. Be that as it may, within the frameworks made by water adsorption on the nano-SiO_2 surface under the impact of γ-quanta, the radiation-chemical surrender of atomic hydrogen from water decay was less than 0.36 molecule/(100 eV). This implies that the surface vitality exchange centered on the nano-SiO_2 surface is exceptionally thin. When the interparticle space is filled with water, the radiation-chemical surrender of the electrons radiated from the strong surface to the fluid stage increases, and as a result, the radiation-chemical surrender of the atomic hydrogen obtained by responses (13–16) also increases.

Conclusions

It is known from the research that, under the influence of γ-quanta (^{60}Co, $P = 9.276$ rad/s, $T = 300$ K), the radiation-chemical yield of molecular hydrogen obtained from radiolysis processes occurring with a change in water mass $m_{H_2O} = 0.001 \div 0.8$ g in created nano-SiO_2/H_2O systems with a mass of $m = 0.2$ g and a particle size of $d = 20$ nm:

- ✓ decreases, $G(H_2) = 22.5–1.11$ molecule/100 eV, if determined for the water,
- ✓ increases, $G(H_2) = 0.29–4.45$ molecule/100 eV, if determined for the nano-silica, and
- ✓ increases, $G(H_2) = 0.27–1.47$ molecule/100 eV, at a value of water mass $0.001\ g \leq m_{H_2O} < 0.2$ g, reaches maximum $G(H_2) = 1.66$ molecule/100 eV at a value of water mass $m_{H_2O} = 0.2$ g, and gradually decreases $G(H_2) = 1.26–0.89$ molecule/100 eV at a value of water mass $0.2\ g < m_{H_2O} \leq 0.2$ g if determined for the total system.

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Data availability statement. The data used in this study are available upon request to the corresponding author.

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Authorship contribution. Y.D.J. performed the experimental work, analyzed the data, and wrote the manuscript. S.M.B., I.J.M., and G.T.I. interpreted the data and produced the figures. G.T.I. edited and revised the manuscript.

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Conflict of interest. The authors declare no conflicts of interest.

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Peer Reviews

Review 1: Obtaining Molecular Hydrogen from Water Radiolysis in the nano-SiO2(d = 20 nm)/H2O System under the Influence of γ -Quanta

Reviewer: Dr. Barbara Pastina

Posiva Oy, Olkiluoto, Finland, 27160

Date of review: 05 February 2023

Conflict of interest statement. Reviewer declares none.

Comment

Please specify if the results in Figure 1 and Figure 2 are experimental results or theoretical ones. If they are experimental results, the error bars should be shown. If they are theoretical ones, this should be mentioned in the text and in the figure caption.

Please comment and compare the G(H2) in Figure 2 with those in the literature addressing similar silica/water systems, especially those in reference [17].

Has this paper shown something new or confirmed the earlier results?

Score Card

Presentation

3.6 /5

Is the article written in clear and proper English? (30%)	4/5
Is the data presented in the most useful manner? (40%)	3/5
Does the paper cite relevant and related articles appropriately? (30%)	4/5

Context

4.0 /5

Does the title suitably represent the article? (25%)	5/5
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Does the introduction give appropriate context? (25%)	4/5
Is the objective of the experiment clearly defined? (25%)	4/5

Results

3.0 /5

Does the discussion adequately interpret the results presented? (40%)	3/5
Is the conclusion consistent with the results and discussion? (40%)	3/5
Are the limitations of the experiment as well as the contributions of the experiment clearly outlined? (20%)	3/5

doi:10.1017/exp.2023.5.pr2

Review 2: Obtaining Molecular Hydrogen from Water Radiolysis in the nano-SiO2(d = 20 nm)/ H2O System Under the Influence of γ -Quanta

Reviewer: Dr. M. R. S. McCoustra

Date of review: 07 February 2023

Conflict of interest statement. Reviewer declares none.

Comment

This paper reports on the radiolysis of a water / nano-silica system and observations of H2 formation. This paper adequately describes the measurements and their interpretation. In places it was a little difficult to read and might be improved by asking a native English speaker to review the language rather than the scientific content of the paper which is fine.

My only minor issue is that the authors talking about silicate in several places. I assume that they mean silica?

Score Card

Presentation

4.0 /5

Is the article written in clear and proper English? (30%)	3/5
Is the data presented in the most useful manner? (40%)	4/5
Does the paper cite relevant and related articles appropriately? (30%)	5/5

Context

4.0 /5

Does the title suitably represent the article? (25%)	4/5
Does the abstract correctly embody the content of the article? (25%)	4/5
Does the introduction give appropriate context? (25%)	4/5
Is the objective of the experiment clearly defined? (25%)	4/5

Results

4.0 /5

Does the discussion adequately interpret the results presented? (40%)	4/5
Is the conclusion consistent with the results and discussion? (40%)	4/5
Are the limitations of the experiment as well as the contributions of the experiment clearly outlined? (20%)	4/5