

Q4 This question is about coronavirus testing

A typical lateral flow test works by a sample liquid flowing along a paper medium (from left-to-right in the picture). Lateral flow tests for COVID-19 use the strong binding between spike proteins on the surface of virus particles and antibodies to detect coronavirus. The red/pink colour in many lateral flow tests is from gold nanoparticles coated with antibodies.



To use a particular lateral flow test, a swab is taken and placed in 1.0 cm^3 extraction solution containing $7.3 \text{ mmol dm}^{-3} \text{ Na}_2\text{HPO}_4$ and $4.6 \text{ mmol dm}^{-3} \text{ KH}_2\text{PO}_4$ at pH 7.4 at $25 \text{ }^\circ\text{C}$.

- (a) What is the purpose of these chemicals in the extraction solution? Tick the correct answer in the answer booklet.

Make a very acidic solution

Make a neutral solution

Make a very alkaline solution

Make a buffered solution

- (b) If 1.0 cm^3 of $0.10 \text{ mol dm}^{-3} \text{ HCl}$ were then added to the extraction solution, what pH would the resulting solution be? Tick the correct answer in the answer booklet.

Very Acidic

Neutral

pH 7.4

Very Alkaline

During the test a person swabs their nose/throat and places it in the extraction solution. The resulting solution is called the test solution. A test sample of a few drops (0.10 cm^3) of the test solution are placed on the sample pad.

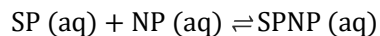
If the person taking the test has COVID-19, there will typically be 7.1×10^6 virus particles per cm^3 in the test solution. Each virus particle has approximately 20 spike proteins on its surface.

- (c) What is the concentration of spike proteins, [SP], in the test sample placed on the pad in mol dm^{-3} ?

If you do not get an answer, use $[\text{SP}] = 1.0 \times 10^{-11} \text{ mol dm}^{-3}$ in subsequent calculations.

Once the sample passes the conjugate pad, it becomes saturated with red-coloured antibody-coated Au nanoparticles (NP), to a concentration $1.6 \times 10^{12} \text{ NP per cm}^3$.

An equilibrium is set up where the NP bind to any spike proteins, SP. Assume that any binding that takes place between spike proteins and nanoparticles is 1:1.



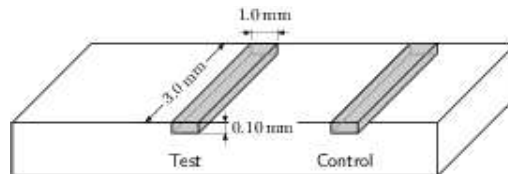
$$K = \frac{[\text{SPNP}]}{[\text{NP}][\text{SP}]} = 1.2 \times 10^{10} \text{ mol}^{-1} \text{ dm}^3$$

- (d) As there is a large excess of nanoparticles, you can assume that the concentration of nanoparticles at equilibrium is still 1.6×10^{12} NP per cm^3

Determine $[\text{SPNP}]$ at equilibrium in mol dm^{-3} .

If you do not get an answer, use $[\text{SPNP}] = 1.0 \times 10^{-11}$ mol dm^{-3} in subsequent calculations.

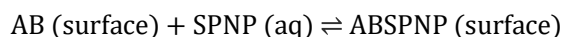
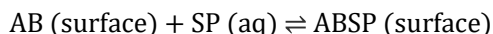
The resulting mixture flows over the test strip which contains surface-immobilized antibodies (AB). When considering the amount of a substance on a surface, we use surface density, σ_A , instead of concentration.



The test strip is 3.0 mm long, 1.0 mm wide and 0.10 mm deep, with a surface density of antibodies, $\sigma_{AB} = 1.2 \times 10^9$ mm^{-2} .

- (e) (i) Calculate how many surface-immobilized antibodies, AB, there are on the test strip surface.
- (ii) Calculate how many free spike proteins, SP, and how many nanoparticle-bound spike proteins, SPNP, are present in a volume of solution of the size of the test strip before any interaction with the test strip.

The surface-immobilized antibodies, AB, bind to any spike protein present (free SP and nanoparticle-bound SPNP) with the following equilibria:



These have the same equilibrium constant:

$$K = \frac{\sigma_{\text{ABSP}}}{\sigma_{\text{AB}}[\text{SP}]} = \frac{\sigma_{\text{ABSPNP}}}{\sigma_{\text{AB}}[\text{SPNP}]} = 3.3 \times 10^{10} \text{ mol}^{-1} \text{ dm}^3$$

- (f) Determine the number of nanoparticles immobilized on the test strip, ABSPNP, once the whole 0.10 cm^3 test sample has fully flowed past.

The visibility of the test line depends on the number of nanoparticles which become immobilized on it. Nanoparticles are visible down to a surface density of 3×10^6 NP per mm^2 .

- (g) Determine the minimum number of virus particles present in the test sample which would give a positive result.