Catalase

Introduction
Teachers who have not used the problems before should read the section Using the problems before starting.

Prior knowledge
General knowledge about catalysts and enzymes, and Avogadro's number. A detailed knowledge is unnecessary as students are encouraged to consult textbooks and data books during the exercise.

Resources
Scientific calculators, data books and textbooks for reference.

Group size
3–4.

Possible solutions
Question (i) requires the exercise of judgement and the ability to make sensible 'guesstimates'. Students are generally not accustomed to this in a scientific context and may feel uncomfortable, but push them into guessing suitable figures. Get them to think; give them help when required, but only as much as is necessary.

Questions (ii) and (iii) involve straightforward arithmetic while question (iv) does not involve any calculation.

(i) Students are forced into making an assumption (guess) based upon inadequate information – 1 g of blood on the handkerchief is assumed in the following calculation.

If 1 g of blood contains 0.0001 g catalase then there is (0.0001/33000) mole catalase or (0.0001/33000) x 6.0×10^{23} molecules of catalase
= 1.8×10^{15} molecules.

(ii) Number of peroxide molecules decomposed per minute
= $1.8 \times 10^{15} \times 5 \times 10^{6} = 10^{22}$.
Compare these figures with:

- the UN estimate for the 1990 world population = 5.25×10^{9};
- the number of cells in a 12-stone man = 10^{14}; and
- the number of cells in the largest living creature, the blue whale = 10^{17}.

H_2O_2, molecular mass = 34

$$\text{Mass decomposed per minute} = \frac{10^{22}}{6 \times 10^{23}} \times 34$$

= 0.62 g hydrogen peroxide

(iii) 50 g detergent, 2 % hydrogen peroxide, ie 1 g of hydrogen peroxide. This would last between 1–2 minutes.

(iv) The problem of enzyme deactivation would be greatest in Japan where all major brands of detergent contain enzymes. Washing at high temperatures would deactivate both the enzyme in the blood and the enzyme in the detergent although the bleach would still work. Bleach, however, is not as effective as enzymes for biological stains.
A low-temperature prewash would allow the enzymes in the detergent to digest the blood stain, and an ordinary main wash thereafter would allow both the enzymes and the bleach to work.

Other solutions include

- multicomponent detergents. These consist of non-woven rayon sheets on which the different components are deposited in small piles. A second sheet is then laminated on top of the first, keeping the different components isolated. The consumer tosses one or more of these sheets into the washing machine. Until now these have been used to separate fabric conditioner from the other components. The conditioner is encapsulated in wax, and it is the heat of tumble drying that melts the wax and releases the conditioner at the right time; and
- applied biology. Enzymes are inhibited by low molecular weight molecules or by other proteins. It has been observed that tumour tissue from liver does not catalyse the decomposition of hydrogen peroxide as well as normal tissue because the tumour tissue makes a protein that inhibits catalase. The molecular biologist would purify this protein, determine part of its amino acid sequence and use this to clone the gene that encodes the protein responsible for the inhibition. The protein would be over expressed in harmless bacteria such as Escherichia coli. If the protein could be made cheaply enough it might be added to the washing powder to inhibit the catalase present in blood. At present this technology is quite expensive and is used to provide pharmaceutical proteins such as human growth hormone and blood clotting factors that are in short supply. However, the costs of this type of work inevitably reduce with time so that producing a 'catalase inhibitor' by this route will eventually become economically viable

Suggested approach

During trialling the following instructions were given to students and proved to be extremely effective:

1. Working as a group, discuss the problem and try the calculations. You can divide the work amongst you if you wish but keep each another informed of progress.
   Such discussion can play a vital part in working out solutions to such problems. Several minds working on a problem together can stimulate ideas that one on its own could not manage. About 10 minutes should be spent on this initially, coming together for further discussion as required.
2. Write a brief account of what you did. You should explain how you decided upon the estimates you had to make.
3. Working as a group, prepare a short (ca 5-minute maximum) presentation to give to the rest of the class. If possible all group members should take part: any method of presentation (such as a blackboard, overhead projector, etc) can be used. Outline

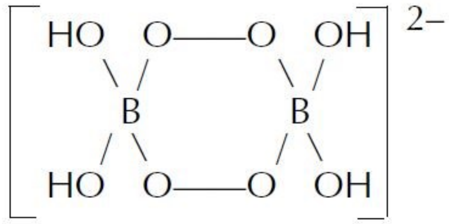
the problem, describe what you did and explain how you arrived at your answer. After the presentation, be prepared to accept and answer questions and to discuss what you did with the rest of the class.

Background information

1. Perborates are more properly called peroxoborates. They are made by treating boric acid with sodium peroxide, or borax with hydrogen peroxide:

$Na_2B_4O_7$(s) + 2NaOH(aq) + 4H_2O_2(aq) + 11H_2O(l) → 4$NaBO_3$.4H_2O(aq)
(borax)

The solid produced can be dehydrated to the monohydrate.
Both solids contain the ion:



They are of good stability but hydrolyse in water releasing hydrogen peroxide.

2. Between 10 % and 20 % of the mass of a detergent is perborate. 100 g of perborate hydrolyses to give up to about 20 g hydrogen peroxide. In solution at 95 °C, sodium perborate releases 90 % of its available oxygen and bleaches heavy soil and wine stains. At 55 ºC it is only 60 % effective. Bleach activators, such as pentaacetyl glucose and tetraacetylethylenediamine, are added to enzyme detergents. These decompose to unstable peracetic acid, which acts as a bleach at low temperatures.

Catalase

From the text below:

I. Estimate the number of molecules of catalase in a blood stain – eg one on a handkerchief with 1g of blood from a bleeding nose.
II. Calculate the number of molecules of hydrogen peroxide, and then the mass, decomposed each minute by this amount of catalase.
III. Calculate how long it would take for the blood stain to decompose all the bleach in, say, 50 g of the detergent used for a normal wash.
IV. In which of the three countries mentioned would the problem of enzyme deactivation be likely to be most acute. Suggest ways of overcoming the problem.

A catalyst is a material that offers an alternative and easier pathway for a chemical reaction to occur. Generally, reaction rate increases with increasing temperature with or without a catalyst. Catalysts in biological systems consist of proteins called enzymes. If the temperature is increased too much, the enzymes are deactivated because their molecules are altered by the heat and they are no longer effective as catalysts.

A change that is currently affecting the soap and detergent industry worldwide is a move toward lower wash temperatures for dishes and for clothing. Until recently a clothes 'hot wash' in Europe was 90 °C, whereas in the USA and Australia it was 55 °C. In Japan, the usual wash temperature is 30 °C or below. Enzyme activated products are now used for effective cleaning at low temperatures. In the USA these account for about 50 % of the market and in Europe about 75 %, while in Japan all major brands were reformulated with enzymes as long ago as 1978.

Detergents contain materials such as sodium perborate to bleach out stains. In water, about 2 % of the detergent's weight is released as hydrogen peroxide, a powerful oxidising agent which can remove a lot of staining while generally leaving fast colours unaffected. Bleaching works well when the material is left to soak for some time but a fairly high concentration is required for it to be effective during the wash, and it works best at high temperatures.

Catalase is an enzyme, molecular mass 33 000, that is present in many biological stains to the extent of about 0.01 %. Unfortunately, it destroys bleach at room temperature: one molecule can destroy roughly 5×10^6 molecules of hydrogen peroxide per minute.

These problems are not unusual: many real-life problems do not have simple definitive solutions. Sometimes there is no precise answer but more often the solution depends upon an assessment of imprecise ('soft') data, a balance of probabilities and even the attitudes of the person concerned.

You should refer to any sources of information that you think might help such as your notebooks, textbooks and data books. Ask for assistance if you get stuck.