**Waking Up Anna**

By Kate O’Toole1, and Shuchismita Dutta2\*

1Department of Biology, Emory University, Atlanta, GA 30322

2Institute of Quantitative Biomedicine, Rutgers University, Piscataway NJ 08854

\*contact author: sdutta@rcsb.rutgers.edu

**Preparation:**

As homework, prior to the case discussion in class, get acquainted to the case.

* Watch a video (<https://www.youtube.com/watch?v=V9gnvWtta4M>) to hear Anna’s personal account and how doctors at the Emory Sleep Center in Atlanta, GA found a treatment that finally helped her feel awake.
* Read the Emory news article, “An antidote for hypersomnia”, by Baker and Eastman, published on Nov. 21, 2012 describing this treatment (<http://news.emory.edu/stories/2012/11/antidote_for_hypersomnia/>).
* Read the abstract of the peer reviewed scientific article describing this work at <https://stm.sciencemag.org/content/scitransmed/4/161/161ra151.full.pdf>

These articles and video set the stage for the case. In order to understand how and why Anna woke up following the specific treatment given to her it will be helpful to learn a little about cellular communication in the brain, neurotransmitters, and their receptors (especially the ones involved in sleep). At the same time learning the vocabulary and key concepts of related to neurochemistry of sleep and sedatives will help in understanding the molecular basis for the cause and treatment of Anna’s sleep crises.

* Review these sub-sections and answer the questions below.

*A. Understanding sources*

Based on the video you watched and articles you have read about this case answer the following questions.

Q1. Describe in 1-2 sentences the main difference between the popular news report and the peer-reviewed scientific article.

Q2. For the three sources of information that you viewed/read for this case list one benefit and one drawback in the table below.

|  |  |  |
| --- | --- | --- |
| Source | Benefit | Drawback |
| Video |  |  |
| News report |  |  |
| Journal article |  |  |

Q3. Define the prefixes Hypo- and Hyper- used in the description of this case in the peer-reviewed manuscript. Find at least one example where this meaning is used

*B. Cellular Communication in the Brain*

Anna’s doctors guessed that there was something off balance between the excitation and inhibition systems in her brain, which might be causing her extreme sleepiness. To understand her condition, we must first understand normal cellular communication works in the brain and how it is inhibited in sleep.

**Neurons** are cells in the nervous system that transmit information to other nerve cells, muscle, or glands in the body to changes its physiology and elicit a response. Communication between neurons and other cells is carried out by small chemicals called neurotransmitters. The space between the 2 cells is called the **Synapse**. (see Figure 1). When a suitable electrical/chemical signal reaches end of the pre-synaptic cell it causes vesicles full of the neurotransmitter to be released into the synapse. Specific receptors on the surface of second (pos-synaptic) cell binds it and sends a signal.



Figure 1: Neuronal synapse showing a presynaptic cell, post synaptic cell, neurotransmitters, synaptic vesicles, and receptors

Q4. Match the names listed in column A with the Label numbers of Fig 1 (listed in column B).

Ans:

|  |  |
| --- | --- |
| Column A | Column B |
| Neurotransmitters | 4 |
| Synaptic vesicle |  |
| presynaptic cell |  |
| postsynaptic cell |  |
| receptors |  |

* Review the vocabulary in Box 1 to learn more about signaling in the brain and answer the following questions

*Box 1: Vocab*

**Neurotransmitters** are small molecules derived from basic building blocks of life, e.g., amino acids. For example, gamma amino butyric acid (or GABA) is derived from the amino acid Glutamate by a decarboxylation reaction. They bind to proteins (such as receptors) and affect their functions. They are also referred to as ligands and may include naturally occurring molecules or man-made drugs.

**Receptors** are large transmembrane proteins that change shape when they bind to small molecules. Many clinically important drugs also bind to receptors in the brain to change our behavior, to treat diseases, and in special situations like inducing anesthesia for surgery.

There are many different combinations of neurotransmitters and receptors in the nervous system that add together to control the types of physiological and behavioral responses that we can see in ourselves. Two main types of neurotransmitter receptors are listed here:

1. **Metabotropic** receptors control metabolic pathways inside the cell, which can change the activity and expression of proteins.
2. **Ionotropic** receptors open pores, or channels, to allow specific ions to cross the cell membrane. These “ion channels” alter the electrical properties of the membrane to increase or decrease the likelihood that the cell will continue the chain of communication by firing an action potential.

Some neurotransmitters (e.g. glutamate) are excitatory (i.e., make it easier to fire action potentials while others (e.g., GABA) are inhibitory (i.e., make it harder to fire action potentials).

Q5. Review Figure 1 and examine what happens to the receptors when the neurotransmitter binds. Does it open or close? What can you say about the type of neurotransmitter receptor shown in figure 1?

*C. Neurochemistry of Sleep*

Normal brain function relies on a balance between inhibitory signaling mediated by the molecule GABA and excitatory signaling driven by Glutamate. Key players involved in inducing sleep are discussed here.

* Neurotransmitter: The chemical **GABA** (gamma-amino butyric acid) is one of the main **inhibitory** chemicals of the nervous system. It dampens/slows down brain activity and promotes sleep.
* Receptor: There are two main types of GABA receptors. GABA type A (GABA-A) receptors are ionotropic and GABA type B (GABA-B) receptors are metabotropic, but the overall response of both types of receptors is to inhibit the activity of the cell.
* Structure and Function of GABA-A receptors:
  + Structure: These receptors are pentameric, i.e., they are composed of 5 transmembrane protein subunits that together form a chloride ion-selective channel. Although there are many different isoforms of the protein, the most common type of GABA-A receptors found in the human brain are composed of 2 alpha (**α**), 2 beta (**β**), and 1 gamma (**γ**) subunit.
  + Function: Binding of neurotransmitters triggers ion channels to open. When GABA binds to the GABA-A receptor, the ion channel is open and chloride ions can cross the cell membrane. Other ligands, including clinically important drugs, *e.g.* benzodiazepines (a sedative), anesthetics and depressants can also bind to the GABA-A receptor to alter its function by opening or closing the Cl− channel. A simple cartoon of the GABA-A receptor is shown in Figure 2 along with the binding sites of various ligands.

A close up of text on a white background

Description automatically generated

Figure 2: GABA-A receptor, chloride (Cl−) ionophore complex. The cut-away view shows binding sites for a variety of compounds that influence the function of the receptor complex. (Adapted from Olsen, R.W. and DeLorey, T.M., (1996), GABA Receptor Physiology and Pharmacology, Basic Neurochemistry: Molecular, Cellular and Medical Aspects. 6th edition.)

* Key vocabulary often used in describing the binding of drugs and small molecules to their target receptors is included in Box 2.

*Box 2: Vocab*

**Agonists**: These are drugs or molecules that turn on the function of a protein. The natural ligand usually acts as an agonist.

**Antagonists**: These are drugs or molecules that decrease or inhibit the function of a protein.

**Allosteric modulators**: The word root “allo” means “other”. These are drugs or molecules that bind at a location other than the natural ligand’s binding site. Modulators could be positive (increase activity of the protein) or negative (decrease its activity).

* Based on what you have learned here answer the following questions.

Q6. The GABA-A receptor is a transmembrane protein. Where would you expect a chemical signal (GABA, Benzodiazepine etc.) to bind this receptor? Circle ONE and explain your choice.

1. extracellular side
2. transmembrane domain
3. intracellular side
4. in the central channel

Explanations:

Q7. Complete the following table describing the effect of ligand/ drug binding to the GABA-A receptor.

|  |  |  |
| --- | --- | --- |
| # | Ligand/Drug bound | Effect on Chloride channel |
| 1 | Agonist |  |
| 2 | Positive Allosteric Modulator |  |
| 3 | Antagonist |  |
| 4 | Antagonist as above + high concentration of GABA |  |

Explanations:

**Part 1: A Clue in Anna’s Spinal Fluid**

Although we have all may have been sleep deprived at some point in time and can relate to how difficult it becomes to focus or carry out simple routine tasks, Anna Sumner’s case was different – she craved sleep and would not be able to wake up refreshed even after ~30 hours of sleep.

Before discussing Anna’s case any further let us review “Neurochemistry of Sleep” that you learned about in part C. of the Preparation section of this case.

Review the structure and function of GABA-A receptors and some key vocabulary terms used in the case (Agonist, Antagonist, Allosteric modulators).

Back to Anna’s case - After excluding known causes of sleepiness, doctors stopped all stimulants and drugs that were being prescribed to Anna to collect a sample of her cerebrospinal fluid (CSF). The doctors were looking for clues about the unique pharmacology within her sleepy brain. Researcher scientists analyzed her sample along with 31 similarly hypersomnolent patients and found a substance that increased GABA-A receptor function in cultured cells!

Let’s examine some key evidence that scientists gathered to help understand Anna’s case.

*Box 8: Experimental techniques*

Ions, like Na+, K+, Ca2+, and Cl−, are present in different concentrations inside and outside neuronal cells leading to a **membrane potential** difference in charge. When channels are open, ions can move across cellular membranes according to the concentration and electrical gradients, leading to rapid and transient changes in distribution of these charged particles. Movement of ions is recorded as **current** and these electrical signals are transmitted through neurons to trigger physiological changes.

**Patch clamp** is an experimental technique used to measure changes in electrical properties of cell membranes to determine whether or not the channels in these receptors are open or closed in the presence of different ligands.

When GABA-A receptor channels are closed there is a baseline reading. In these experiments, GABA and/or other GABA-A receptor agonists open the chloride channels to let negative ions (Cl−) into the cells. The patch clamp records this entry of Cl− ions as a downward deflection from the baseline. The larger the deflection (or dip) in the recording the more the Cl− ions have entered, inhibiting the neuron.

Scientists used patch clamp electrical recordings on a specific cell line with GABA-A receptors to measure currents triggered by the following:

|  |  |  |
| --- | --- | --- |
| Trace | What was added | Why was it added |
| a | 10 μM GABA alone | control to establish a baseline |
| b | Hypersomnolent patient CSF alone | To see if the CSF factor can work alone |
| c | Hypersomnolent patient CSF + 10 μM GABA | To see if the CSF factor impacts GABA binding and GABA-A receptor function |
| d | Flumazenil, a competitive antagonist + Hypersomnolent patient CSF + 10 μM GABA | To see if the CSF factor binds to the benzodiazepine binding site |
| e | Flumazenil, a competitive antagonist + 10 μM GABA | Control to see that Flumazenil does not interfere with GABA binding |
| f | normal GABA concentrations in typical CSF | Control after all pharmacological agents were washed away |

Review the chloride currents seen for each of these cases and answer the following questions.

A picture containing diagram, text

Description automatically generated

Figure 3. Chloride currents recorded from HEK293 cells expressing human GABA-A receptor. Vertical axis (current) calibration bars equal 200 pA (picoAmps) and horizontal axis (time) calibration bars equal 5 s.

Q1. Compare the chloride current traces shown in b. and c. and explain the conclusion that can be drawn from your observation.

Ans:

Q2. Compare the chloride current traces shown in c. and d. and explain the conclusion that can be drawn from your observation.

Ans:

Q3. Based on the traces above, which of the following statements is correct?

1. Only in trace c. the GABA-A receptor is open and Cl− ions are flowing into the cell
2. The substance in Anna’s CSF can bind to GABA-A receptor and open the Cl− channel
3. The substance in Anna’s CSF needs GABA in order to open the Cl−channel
4. Flumazenil can close the GABA-A receptor Cl− channels
5. When the GABA-A receptor is open K+ ions are flowing out of the cell

Q4. Based on the results presented, where in the GABA-A receptor do you think the CSF factor binds?

Ans:

**Part 2: Molecular Basis of Sleep**

To better understand Anna’s story in molecular detail we need to understand the structure and function of the GABA-A receptor.

*A. GABA- A Receptor Structure*

In this section we will explore known structures of the GABA-A receptor to learn more about its shape and structure. The resource for accessing molecular structures of GABA-A receptors is the Protein Data Bank.

*Box 3: Resource*

RCSB Protein Data Bank (**RCSB PDB**, [www.rcsb.org](http://www.rcsb.org)) provides access to 3D structural data of biological macromolecules (proteins, nucleic acids, carbohydrates and their various complexes). In addition, it provides information about the experiment used to derive the data, details about the molecules included in the experiment, and links to bioinformatics resources that can provide additional information about the protein/molecule of interest. Each structure in the PDB has a unique identifier called PDB ID. Atomic coordinates form the PDB can be explored and analyzed using various visualization software (e.g., Jmol, Pymol, UCSF Chimera, iCn3D).

* Search for “GABA-A receptor” in the PDB ([www.rcsb.org](http://www.rcsb.org)) by typing in the protein name in the top search box.

Q1. How many structures of the GABA-A receptor did you find in the archive? Why are there so many structures?

* Click on the **PDB ID 6i53** to open the structure summary page for this entry. This is the structure of a human GABA-A receptor. Review Box 5 and answer the following questions.

*Box 4: Navigating the Structure Summary Page*

1. **Title** - that tells you what the structure is about

2. **Snapshot** - of what the structure of the molecule/complex looks like.

3. **Authors** – who solved the structure

4. **Literature** –access the article that describes the structure. This section also includes links to PubMed page and the abstract of the article describing this structure, when available.

5. **Macromolecules** – All proteins and nucleic acids present in the structure are listed here. Each unique type of macromolecule or molecular chain is listed as a separate entity. There may be multiple copies of each molecule in the structure.

6. **Small molecules** – All ligands, ions, cofactors, inhibitors that are present in the structure are listed here. You can find links here to explore the interaction of this ligand with the target protein.

7. **Experimental details** – describe details about how the structure was determined

8. **Structure quality** – shows a slider that provides insights about the quality of the structure and its agreement with the experimental data and geometric standards.

See <http://pdb101.rcsb.org/learn/guide-to-understanding-pdb-data/introduction> for details

Q2. Explore the structure summary page to learn about the contents of the structure and fill in the table.

Ans:

|  |  |
| --- | --- |
| PDB ID | 6i53 |
| Author(s) of entry |  |
| Year when the structure was published/ released |  |
| Structure determination method |  |
| # of entities |  |
| # of polymer chains |  |
| Names of proteins in these chains (chain ID) |  |
| # of different small molecule ligands in the structure and their identifiers |  |

Q3. Why do some of the protein subunits list multiple chain IDs on the structure summary page?

Ans:

* Before you explore the structures of the GABA-A receptor any further, review Box 6.

*Box 5: Vocab*

**Residues**: Building blocks of biological macromolecules are sometimes referred to as residues. Depending on the context, this may refer to amino acids (frequent use) or a nucleotide (less common use).

**Chains**: The term chain is used to refer to covalently linked amino acids (polypeptide). Some proteins structures contain more than one polypeptide - each subunit of this structure is referred to as a chain. To help locate amino acids in the structure, each chain is given an identifier (called Chain ID) and each amino acid in the chain is assigned a number.

**Domains** are conserved parts of a protein that can evolve, function, has a stable three-dimensional structure and often can stably fold and exist independently (of the full protein). On the other hand, loops and linker regions between domains are often flexible and cannot be clearly seen in experimental structures. Their atomic coordinates may be missing from the file because the large protein was cut into smaller pieces and only the relevant structures are included in the experiment OR they were present in the experiment, but its location could not be seen due to high mobility.

**Complex assembly and stability**: Protein complexes can be assembled in vitro (outside the cell) to study the structure. In order to stabilize the assembly additional ligands or even polymer chains may be included in the experiment – for example

a. lipid-like or detergent molecules are included in membrane protein complexes to prevent them from aggregating or precipitating from the aqueous solutions

b. antibodies, parts of antibodies, nanobodies, megabodies, or other stable proteins/domains may be included in the experiment to facilitate assembly formation, enhance solubility of the complex, or trap the molecule/complex in a specific conformation.

* Click on the 3D View tab on the Structure summary page and view the molecular structure of the GABA-A receptor.
* Interactively rotate and reorient the structure to get acquainted with it.
* Spend a few minutes playing around with the different menus to see some of the different ways this protein view can be adjusted.

Q4. Can you identify the extracellular ligand binding domains and transmembrane domains in the GABA-A receptor structure? Which type of secondary structural elements (helices or sheets) make up these domains?

Ans:

Q5: Make an image with the extracellular domain on top. Label the extracellular domain, the transmembrane domain and the megabody. Include the image below.

Ans:

In order to visualize and analyze the GABA-A receptor complexes in greater detail we will use an online molecular structure visualization tool, called iCn3D.

*Box 6: Resource*

**iCn3D** is a web-based visualization tool that allows users to directly open any structure from the Protein Data Bank (PDB) and visualize the structure. Users can interactively rotate the molecule/complex, select specific regions and represent them in different ways, compare structures, analyze interactions and make simple distance measurements.

* Go to iCn3D (<https://www.ncbi.nlm.nih.gov/Structure/icn3d/full.html>)
* Click on the button called File >> Retrieve by ID >> PDB ID so that a new window opens. Input the PDB ID of the structure you wish to visualize (e.g., 6i53) and click on Load.
* The structure opens in a new tab – rotate the molecule and examine the overall structure.
* Spend a few minutes playing around with the different pull-down menus to see some of the different ways this protein view can be adjusted.
* Orient the molecule to view it from the side, the extracellular domain is on the top and the transmembrane domain is below. Save an image of this view:
  + Click on File >> Save files >> iCn3D PNG image
  + Import the image saved above to power point or any other graphics software and label in the image appropriately.

Q6. How many polymer chains do you see? Explain how you figured out this answer and include the image you saved and labeled below.

Ans:

* Color the structure by secondary structure as follows: Click on Color >> Secondary >> Sheet in Yellow. Save an image.

Q7. Describe the distribution of the secondary structural features in this image.

Ans:

Although the 5 protein chains or subunits of the pentameric GABA-A receptor are proteins with different amino acid sequences, their overall shape and structure is very similar. Here we will examine the structure of one of these subunit proteins.

* Click on the button Select >> Defined Sets >> a new window opens titled Select sets >> click on 6I53\_A to select it. Notice that the protein chain with identifier A, lights up with a yellow halo in the graphics window.

Q8. What is the name of the protein in chain A? (Hint: Refer back to the structure summary page for this PDB entry to find out the name of the protein. Alternatively, you can also consult your table in Answer 2 of this Part)

Ans:

* To hide the other chains, (and only see the protein with chain ID A):
  + click on Select >> Inverse - to highlight all other proteins and ligands in the structure (except chain A).
  + click on Style >> Proteins >> Hide to hide all currently selected protein chains
  + click on Style >> Chemicals >> Hide to hide all ligands shown in stick representation.
  + click on Style >> Side Chains >> Hide to hide any side chains that were shown in the selected chains.
  + click on View >> Disulfide Bonds >> Hide to hide all disulfide bonds shown.

What remains in the graphics window is the protein chain A (and a few amino acid side chains).

* + Select chain A (as described above) and color >> spectrum. This colors that chain A from N- to C-terminus according to the rainbow color scheme (N-terminus is colored Violet/blue to C-terminus, shown in red).

Q9. What is the main secondary structural element in the N-terminal domain? Is this outside or inside the cell? What is the main secondary structural element in the C-terminal domain? Is this outside or inside the cell? Include an image to support your answer.

Ans:

***Optional advanced structure exploration***:

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The GABA-A receptor proteins belong to the Cys-loop receptors. Each chain in this receptor has a disulfide (S-S) bond and the stretch of amino acids between the linked Cys form the Cys-loop.

* Identify the Cys forming these S-S bonds in each of the 5 chains.
  + Click on View >> Disulfide bonds >> Export pairs. Open the results in a browser window.

Q10. Which residues form the S-S bond in chain A?

*Note: The residue numbers that you read by hovering your mouse over residues in the iCn3D graphics display are the NCBI numbers, you have to find the corresponding the PDB/UniProt numbers from the Sequences and Annotation window.*

Ans:

* Find the C (for Cys) in the sequence window representing Cys 136 and 153. In this window, click and drag on all the residues between these residues to select these residues in the graphics window too.
* Color the selected residues by clicking on Color >> Unicolor >> magenta (or any other color of your choice that stands out). Save an image or take a screenshot of this structure.

Q11. Where in the structure is the Cys-loop located? Show the figure you saved above and explain why this region may be important in the function of the protein.

Ans:

Now that we have some understanding of the structure of each of the GABA-A receptor proteins let us examine the gate through which the chloride ions enter the cell.

* Reload the iCn3D page for the PDB entry 6i53 to see the full structure again.
* You can toggle off the membrane representation by clicking on View >> Toggle Membrane.
* Select Chain A (see instructions above) and color it by the Spectrum option (N-terminus violet/Blue to C-terminus red).
* Orient the structure so that you are looking into the central channel from the inside of the cell.

Q12. Which of the 4 helices in chain A lines the chloride ion channel? (Hint: Helix 1, 2, 3, etc.)

Ans:

Click on any residue on this helix to select an atom and expand the selection by pressing on the up arrow.

Q13. What is the amino acid sequence of this helix? (Hint: Read off the sequence from the sequence window.)

Ans:

\*\*Additional questions can be added here for advanced students to explore the channel from the intracellular face. Compare the diameter of the channel opening by measuring the distance between the Pro in the Helix 2 of 2 alpha chains in the structures with and without GABA bound.

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*B. GABA-A Receptor Function*

In this section we will explore the structure of GABA-A receptor with its natural ligand (GABA) bound to it. This will set the stage for understanding where the ligand binds and how it affects receptor function.

Explore the structure of GABA-A receptor in complex with GABA (PDB ID 6dw0).

* Open the file in iCn3D and explore the structure as above.
* Open the Sequences and Annotations window and scroll to the bottom. Select the 3 ABU ligands – these are the GABA molecules.
* Display these prominently by clicking on Style >> Chemicals >> Sphere.

Q14. Where in the structure are the GABA molecules bound? Outside or inside the cell? Which GABA-A receptor chains are they bound to? Support your answer with a figure.

Ans:

Explore the binding environment of one of the GABA molecules as follows.

* In the sequence window select on the first GABA (ABU) by clicking and dragging on it.
* Now click on View >> H-bonds & Interactions >> Display (with default options)]. by Distance >> use the default options with H-bonds, salt bridges, contacts/interactions checked in the new window that opens and click on Display
* Click on Style >> Side chains >> Sticks; then View >> Zoom in selections; and then Color >> Atom

Q15. List the names of any 2 amino acids whose side chains form hydrogen bonds with the GABA (ABU). Support your answer with a suitable figure.

Ans:

* Examine the interactions of these amino acids with the GABA molecule. Use the following concept box to guide your explorations.

*Box 7: Concepts*

Biomolecular structural stability, interactions and functions are dependent on various non-covalent interactions. Some key interactions in molecular structures are:

**Hydrogen bonds** - formed between two partially negatively charged atoms with a hydrogen atom between and covalently linked to one of them. e.g. in structures look for examples of O/N … H\_\_O/N, where … denotes hydrogen bond and \_\_ denotes a covalent bond

**Salt bridges** or **ionic interactions** - formed between oppositely charged amino acid side chains and/or charged ligands/ions. e.g. in structures look for interactions between Lys/Arg/His and Glu/Asp. These interactions may also involve phosphate groups and ions such as K+, Na+, Cl- etc.

**Hydrophobic interactions** - formed between hydrophobic amino acid side chains positioned away from the aqueous environment. e.g. look for regions with large numbers of carbon and hydrogen atoms in close proximity. Aliphatic amino acids such as Ala, Leu, Val, Ile participate in hydrophobic interactions.

**Pi stacking** - seen between amino acids with aromatic side chains (e.g. Tyr, Trp, Phe). Pi clouds of aromatic rings interact with each other in staggered stacks, face to edge interactions, or interactions with positively charged amino acid side chains (pi-action interaction).

*C. When you Take a Sedative …*

The natural ligand GABA binds to the GABA-A receptor to produce an inhibitory effect by opening chloride channels. What do you think happens to these receptors when individuals who are unable to sleep, take a sedative like valium (a benzodiazepine)? In this section we will explore what happens to the GABA-A receptor when you take valium.

Open another structure – GABA-A receptor in complex with GABA and Valium (PDB ID 6hup). Valium is an example of a benzodiazepine.

* Open the file in iCn3D and explore the structure as above.
* Open the Sequences and Annotations window and scroll to the bottom.
  + Select the GABA molecules (ABU); display these prominently by clicking on Style >> Chemicals >> Sphere; Color >> Atom
  + Select the Valium molecules (DZP); display these prominently by clicking on Style >> Chemicals >> Sphere; Color >> Unicolor >> red.

Q16. Where in the structure are the GABA and Valium molecules bound? Which GABA-A receptor chains are they bound to? Support your answer with a figure.

Ans:

Q17. Based on the location of valium bound in this structure what can you say about the nature of GABA and valium interaction?

Ans:

**\*\***Additional questions can be added here for advanced students to explore the specific non-covalent interactions in the neighborhood of valium (DZP)

**Part 3: Waking up Anna**

The substance in Anna’s CSF was making her sleepy just like the action of benzodiazepine, so her doctors considered testing Flumazenil, a competitive inhibitor of benzodiazepine, to treat her. It worked and Anna woke up (for the first time in many years). Explore the structure of the GABA-A receptor in complex with GABA and Flumazenil to understand where it binds and how it regulates the receptor function.

* Open the file PDB ID 6d6t in iCn3D and explore the structure as above.
* Open the Sequences and Annotations window and scroll to the bottom.
  + Select the GABA molecules (ABU); display these prominently by clicking on Style >> Chemicals >> Sphere; Color >> Atom
  + Select the Flumazenil molecules (FYP); display these prominently by clicking on Style >> Chemicals >> Sphere; Color >> Unicolor >> a color of your choice so that it stands out.

Q1. Where in the structure are the GABA and Flumazenil molecules bound? Which GABA-A receptor chains are they bound to? Support your answer with a publishable figure drawn using iCn3D.

Ans:

**\*\***Additional questions can be added here for advanced students to explore the specific non-covalent interactions in the neighborhood of valium (DZP)

Q2. Based on your explorations of these structures, can you explain the mechanism of Flumazenil’s action in waking up Anna.

Ans:

Q3. With a hand drawn model summarize the structure of the GABA-A receptor (as seen from the outside of the cell). You may use the pentameric structure shown below to draw and mark in the model where GABA, benzodiazepine, and Flumazenil bind. Remember to label the alpha, beta, and gamma chains of the GABA-A receptor.

Ans:

**Part 4: Beyond Waking Up**

Access to adequate quantities of the drug presents a practical problem for Flumazenil to be considered as a cure for hypersomnia. Anna is the only one person in the world who has taken the drug for an extended period of time. Ongoing research is focused on learning more about Anna’s condition and figuring out alternative ways to treat it.

Q1. How would you design the next experiment to figure out if the mechanism that you are proposing can explain Anna’s recovery from hypersomnia (with Flumazenil treatment)?

Ans:

Q2. Briefly describe in 3-4 sentences what experiments you would do and why?

Ans: