Answer ALL questions.

Some questions must be answered with a cross in a box ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 Humans have a nervous system that has a variety of neurones.

(a) The human brain is made up of a number of areas containing many millions of neurones.

Place a cross in the box ☒ that identifies the areas of the brain associated with riding a bicycle uphill.

(i) the decision to ride the bicycle

(1)

☒ **A** cerebrum

☒ **B** cerebellum

☒ **C** hypothalamus

☒ **D** medulla

(ii) initiating an increase in sweating during the ride

(1)

☒ **A** cerebrum

☒ **B** cerebellum

☒ **C** hypothalamus

☒ **D** medulla

(b) Voltage-gated K^+ and Na^+ channels are involved in the transmission of impulses in sensory and motor neurones.

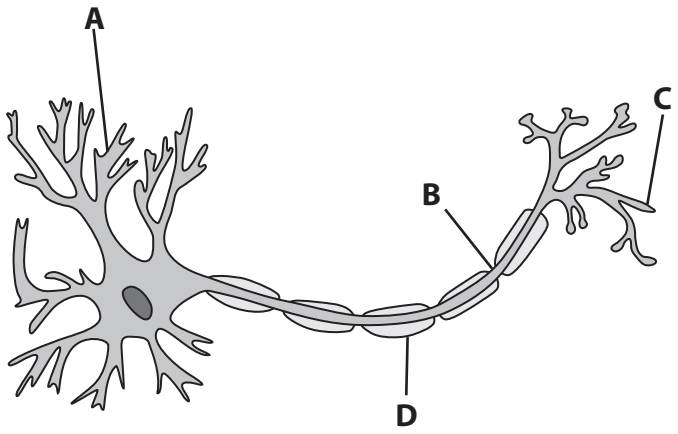
(i) The table below identifies two stages in the transmission of an impulse in a sensory neurone.

Place a tick (✓) in each box that correctly identifies whether the channels are open or closed during these two stages.

(2)

Stage	Voltage-gated K^+ channels open	Voltage-gated K^+ channels closed	Voltage-gated Na^+ channels closed
Depolarisation			
Repolarisation			

(ii) The diagram below shows a myelinated motor neurone.



Place a cross in the box ☒ that labels the site where neurotransmitters bind and initiate depolarisation.

(1)

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(iii) Describe the differences in the structure of a myelinated sensory neurone and a myelinated motor neurone.

(3)

(Total for Question 1 = 8 marks)

2 A human heart can work effectively for over a hundred years but many people throughout the world have heart problems.

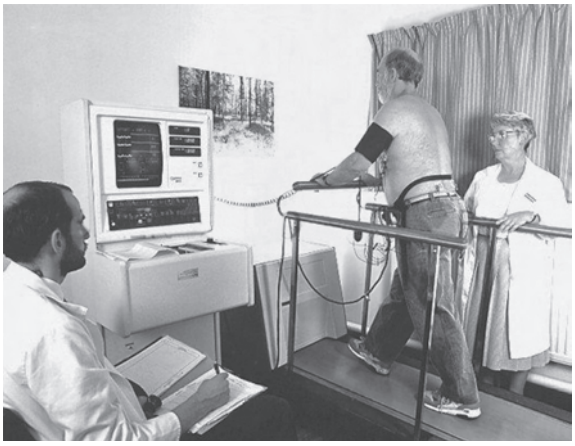
(a) Explain how the sinoatrial node (SAN) ensures that oxygenated blood enters the aorta.

(4)

*(b) The treadmill test can be used to diagnose heart problems.

This test requires a person to walk on a treadmill whilst an electrocardiogram (ECG) is recorded.

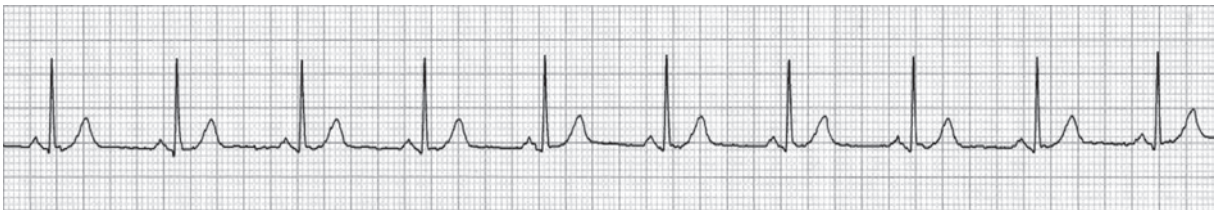
The angle of the treadmill is raised to increase the level of exercise. The photograph below shows a person carrying out the treadmill test.



Explain how the heart rate of this person is controlled as the level of exercise increases during this test.

(6)

(c) The ECG below was recorded at rest.



(i) This person had a resting heart rate of 74 beats per minute.

Calculate the time taken for this ECG. Show your working.

(2)

Answer .....

(ii) Suggest suitable units for the vertical axis (*y*-axis) of this ECG.

(1)

.....

(Total for Question 2 = 13 marks)

3 An investigation was carried out to study the effect of positive and negative physical and emotional experiences on humans.

The positive physical experience was a warm object placed on the arm of a person for five seconds.

The negative physical experience was a hot object placed on the arm of a person for five seconds.

All other variables were kept constant.

Two groups of people were used in this investigation. In the first group, the warm object was used before the hot object. In the second group, the hot object was used before the warm object.

After each experience, the individuals were asked to rate their feelings using the scoring system below.

Feelings	Score
Very bad	1
Bad	2
Neutral	3
Good	4
Very good	5

(a) Suggest why one group had the warm object placed on their arm before the hot object and the other group had the hot object placed on their arm first.

(2)

(b) These two groups were then exposed to a positive emotional experience and a negative emotional experience.

The mean results for the investigation are shown in the table below.

Experience	Mean score for feelings and standard deviation	
	Physical	Emotional
Positive	4.5 ± 0.5	4.2 ± 0.4
Negative	1.9 ± 0.6	1.7 ± 0.4

A student concluded that the physical experiences and emotional experiences were similar.

Using information in the table, comment on the validity of this conclusion.

(4)

(c) This investigation then used a scanning technique to study whether the same areas of the brain were involved in both physical experiences and emotional experiences.

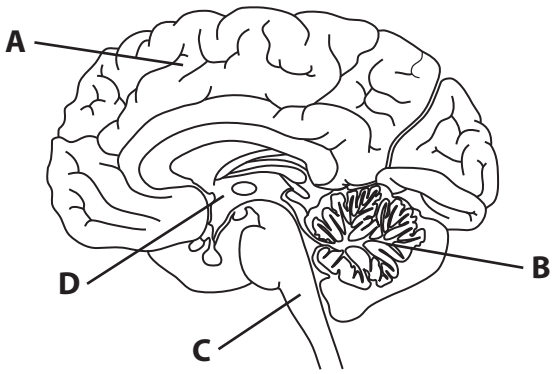
(i) Suggest the scanning technique required to study the brain in this investigation. Give reasons for your choice.

(3)

(ii) It was found that an area of the brain called the insula was involved in both physical experiences and emotional experiences. The insula is found just above the hypothalamus.

Using the diagram below, place a cross in the box ☒ that identifies the area of the insula.

(1)



☒ **A**

☒ **B**

☒ **C**

☒ **D**

(Total for Question 3 = 10 marks)

4 An investigation was carried out to study the effect of light on the mammalian retina.

Part of the retina of a young rat was removed and kept in the dark for two hours. This allowed the pigment in the rod cells to recover from bleaching caused by exposure to light.

(a) Suggest what happens in the rod cells during this two hours of darkness.

(5)

(b) When the retina had recovered from bleaching, the resting potential of the bipolar neurones in the retina was found to be –43 mV.

The retina was then exposed to a range of light intensities. Each light intensity caused the bipolar neurones to depolarise. The peak voltage of the depolarisation for each light intensity was recorded.

All other variables were kept constant.

The investigation used retinas from an additional 14 rats.

The mean results are shown in the table below.

Light intensity / arbitrary units	**Mean peak voltage of depolarisation / mV**
1	11
3	18
6	19
9	20
12	20

(i) Using the information in the table, describe the effect of light intensity on the mean peak voltage of depolarisation.

(2)

(ii) Suggest an explanation for the effect of light intensity on the mean peak voltage of depolarisation in these neurones.

(4)

(c) Suggest **two** reasons why some people might have objections to the use of rats in this investigation.

(2)

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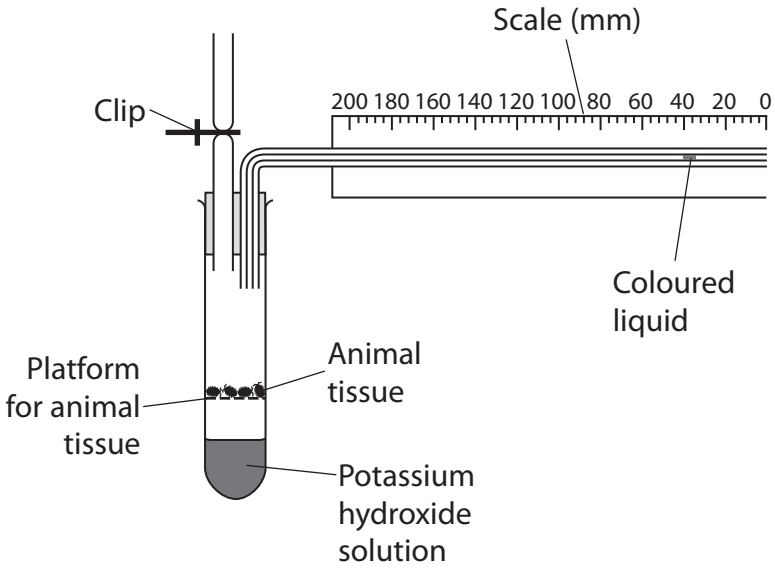
(Total for Question 4 = 13 marks)

5 The tissues of some animals can carry out anaerobic and aerobic respiration.

(a) Three investigations were carried out to study respiration in an animal tissue, using the apparatus shown below.

The tissue used glucose as the respiratory substrate.

All other variables were kept constant.



The table below shows the three investigations that were carried out and the result for investigation 1.

Investigation	Type of respiration	Potassium hydroxide solution absent or present	Coloured liquid moved to the left	Coloured liquid moved to the right	Coloured liquid did not move
1	Anaerobic	Absent	☒	☒	☒
2	Aerobic	Absent	☒	☒	☒
3	Aerobic	Present	☒	☒	☒

(i) Complete the table by placing a cross in one box ☒ for each of investigations 2 and 3 to show the response of the coloured liquid.

(2)

(ii) Explain why the coloured liquid did not move in investigation 1.

(3)

(iii) Reduced NAD (NADH + H^+) would be formed in investigations 2 and 3.

Describe the fate of reduced NAD in aerobic respiration.

(4)

(b) Explain how investigation 3, shown in the table, could be used to compare the rate of respiration of two different tissues.

(2)

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(Total for Question 5 = 11 marks)

6 A number of drugs, including EPO, have been used by athletes.

EPO is a drug that stimulates the formation of red blood cells. EPO has been used to enhance the performance of certain types of athlete.

(a) Sprinters usually have more fast twitch fibres in their leg muscles than long distance runners.

Suggest why EPO may have less of an effect on the performance of a sprinter than on a long distance runner.

(3)

(b) Suggest **two** ethical reasons why the use of drugs, such as EPO, should be banned from sport.

(2)

(Total for Question 6 = 5 marks)

7 The scientific article you have studied is adapted from articles in *Nature* and *Scientific American*.

Use the information from the article and your own knowledge to answer the following questions.

(a) Rabies is a 'nasty infection' caused by a virus (paragraph 5).
Explain how scientists would be able to determine that the rabies pathogen is a virus.

(2)

*(b) Suggest how researchers had genetically modified the pathogen to 'provoke an effective immune response' (paragraph 12).

(6)

(c) Octopamine is a neurotransmitter (paragraph 24). Libersat and his team believe that wasp venom probably blocks octopamine receptors in the central nervous system of the cockroach.

Suggest **two** ways that the 'compound that reactivates octopamine receptors' (paragraph 25) could work.

(2)

(d) Suggest how scientists, such as Hughes, could have estimated that ants comprise 'half of all insect biomass worldwide' (paragraph 31).

(3)

(e) 'While the manipulated individual may look like an ant, it represents a fungal genome expressing fungal behaviour through the body of an ant' (paragraph 33).

Suggest how fungal genes may be expressed and affect the behaviour of these ants.

(5)

(f) Suggest what is meant by the term **clock genes** (paragraph 35).

(2)

(g) Suggest how a lack of 'signals' (paragraph 36) could lead to muscle atrophy.

(4)

(h) 'Instead of one variable species' (paragraph 44), Evans, Hughes and Elliot have identified four new species of the fungus.

Suggest how these could have been identified as separate species.

(4)

(i) There is evidence showing that ants parasitised by the fungus bite the main veins of leaves (paragraphs 35 and 47).

Suggest the advantages to the zombie fungus of this ant behaviour.

(2)

(Total for Question 7 = 30 marks)

TOTAL FOR PAPER = 90 MARKS

Extracts from 'The Immortal Life of Henrietta Lacks'

Prologue
The Woman in the photograph

1. There's a photo on my wall of a woman I've never met, its left corner torn and patched together with tape. She looks straight into the camera and smiles, hands on hips, dress suit neatly pressed, lips painted deep red. It's the late 1940s and she hasn't yet reached the age of thirty. Her light brown skin is smooth, her eyes still young and playful, oblivious to the tumor growing inside her – a tumor that would leave her five children motherless and change the future of medicine. Beneath the photo, a caption says her name is "Henrietta Lacks, Helen Lane or Helen Larson."

2. No one knows who took that picture, but it's appeared hundreds of times in magazines and science textbooks, on blogs and laboratory walls. She's usually identified as Helen Lane, but often she has no name at all. She's simply called HeLa, the code name given to the world's first immortal human cells – *her* cells, cut from her cervix just months before she died.

3. Her real name is Henrietta Lacks.

4. I've spent years staring at that photo, wondering what kind of life she led, what happened to her children, and what she'd think about cells from her cervix living on forever – bought, sold, packaged and shipped by the trillions to laboratories around the world. I've tried to imagine how she'd feel knowing that her cells went up in the first space missions to see what would happen to human cells in zero gravity, or that they helped with some of the most important advances in medicine: the polio vaccine, chemotherapy, cloning, gene mapping, in vitro fertilization. I'm pretty sure that she – like most of us – would be shocked to hear that there are trillions more of her cells growing in laboratories now than there ever were in her body.

5. There's no way of knowing exactly how many of Henrietta's cells are alive today. One scientist estimates that if you could pile all HeLa cells ever grown onto a scale, they'd weigh more than 50 million metric tons – an inconceivable number, given that an individual cell weighs almost nothing. Another scientist calculated that if you could lay all HeLa cells ever grown end-to-end, they'd wrap around the Earth at least three times, spanning more than 350 million feet. In her prime, Henrietta herself stood only a bit over five feet tall.

6. I first learned about HeLa cells and the woman behind them in 1988, thirty-seven years after her death, when I was sixteen and sitting in a community college biology class. My instructor, Donald Defler, a gnomish balding man, paced at the front of the lecture hall and flipped on an overhead projector. He pointed to two diagrams that appeared on the wall behind him. They were schematics of the cell reproduction cycle, but to me they just looked like a neon-colored mess of arrows, squares, and circles with words I didn't understand, like "MPF Triggering a Chain Reaction of Protein Activations."

7. I was a kid who'd failed freshman year at the regular public high school because she never showed up. I'd transferred to an alternative school that offered dream studies instead of biology, so I was taking Defler's class for high-school credit, which meant that I was sitting in a college lecture hall at sixteen with words like *mitosis* and *kinase inhibitors* flying around. I was completely lost.

8. "Do we have to memorize everything on those diagrams?" one student yelled.

9. Yes, Defler said, we had to memorize the diagrams, and yes, they'd be on the test, but that didn't matter right then. What he wanted us to understand was that cells are amazing things: There are about one hundred trillion of them in our bodies, each so small that several thousand could fit on the period at the end of this sentence. They make up all our tissues – muscle, bone, blood – which in turn make up our organs.

10. Under the microscope, a cell looks a lot like a fried egg: It has a white (the *cytoplasm*) that's full of water and proteins to keep it fed, and a yolk (the *nucleus*) that holds all the genetic information that makes you *you*. The cytoplasm buzzes like a New York City street. It's crammed full of molecules and vessels endlessly shuttling enzymes and sugars from one part of the cell to another, pumping water, nutrients, and oxygen in and out of the cell. All the while, little cytoplasmic factories work 24/7, cranking out sugars, fats, proteins, and energy to keep the whole thing running and feed the nucleus. The nucleus is the brains of the operation; inside every nucleus within each cell in your body, there's an identical copy of your entire genome. That genome tells cells when to grow and divide and makes sure they do their jobs, whether that's controlling your heartbeat or helping your brain understand the words on this page.

11. Defler paced the front of the classroom telling us how mitosis – the process of cell division – makes it possible for embryos to grow into babies, and for our bodies to create new cells for healing wounds or replenishing blood we've lost. It was beautiful, he said, like a perfectly choreographed dance.

12. All it takes is one small mistake anywhere in the division process for cells to start growing out of control, he told us. Just *one* enzyme misfiring, just *one* wrong protein activation, and you could have cancer. Mitosis goes haywire, which is how it spreads.

13. "We learned that by studying cancer cells in culture," Defler said. He grinned and spun to face the board, where he wrote two words in enormous print: HENRIETTA LACKS.

14. Henrietta died in 1951 from a vicious case of cervical cancer, he told us. But before she died, a surgeon took samples of her tumor and put them in a petri dish. Scientists had been trying to keep human cells alive in culture for decades, but they all eventually died. Henrietta's were different: they reproduced an entire generation every twenty-four hours, and they never stopped. They became the first immortal human cells ever grown in a laboratory.

15. "Henrietta's cells have now been living outside her body far longer than they ever lived inside it" Defler said. If we went to almost any cell culture lab in the world and opened its freezers, he told us, we'd probably find millions – if not billions – of Henrietta's cells in small vials on ice.

16. Her cells were part of research into the genes that cause cancer and those that suppress it; they helped develop drugs for treating herpes, leukemia, influenza, hemophilia, and Parkinson's disease; and they've been used to study lactose digestion, sexually transmitted diseases, appendicitis, human longevity, mosquito mating, and the negative cellular effects of working in sewers. Their chromosomes and proteins have been studied with such detail and precision that scientists know their every quirk. Like guinea pigs and mice, Henrietta's cells have become the standard laboratory workhorse.

17. "HeLa cells were one of the most important things that happened to medicine in the last hundred years," Defler said.

The HeLa factory

18. Not long after Henrietta's death, planning began for a HeLa factory – a massive operation that would grow to produce trillions of HeLa cells each week. It was built for one reason: to help stop polio.

19. By the end of 1951 the world was in the midst of the biggest polio epidemic in history. Schools closed, parents panicked, and the public grew desperate for a vaccine. In February 1952, Jonas Salk at the University of Pittsburgh announced that he'd developed the world's first polio vaccine, but he couldn't begin offering it to children until he'd tested it on a large scale to prove it was safe and effective. And doing that would require culturing cells on an enormous, industrial scale, which no one had done before.

20. The National Foundation for Infantile Paralysis (NFIP) – a charity created by President Franklin Delano Roosevelt, who'd himself been paralyzed by polio – began organizing the largest field trial ever conducted to test the polio vaccine. Salk would inoculate 2 million children and the NFIP would test their blood to see if they'd become immune. But doing this would require millions of neutralization tests, which involved mixing blood serum from newly vaccinated children with live poliovirus and cells in culture. If the vaccine worked, the serum from a vaccinated child's blood would block the poliovirus and protect the cells. If it didn't work, the virus would infect the cells, causing damage scientists could see using a microscope.

21. The trouble was, at that point, the cells used in neutralization tests came from monkeys, which were killed in the process. This was a problem, not because of concern for animal welfare – which wasn't the issue then that it is today – but because monkeys were expensive. Doing millions of neutralization tests using monkey cells would cost millions of dollars. So the NFIP went into overdrive looking for a cultured cell that could grow on a massive scale and would be cheaper than using monkeys.

22. The NFIP turned to Gey and a few other cell culture experts for help, and Gey recognized the opportunity as a gold mine for the field. The NFIP's March of Dimes was bringing in an average of $50 million in donations each year, and its director wanted to give much of that money to cell culturists so they could find a way to mass-produce cells, which they'd been wanting to do for years anyway.

23. The timing was perfect: by chance, soon after the NFIP contacted Gey for help, he realized that Henrietta's cells grew unlike any human cells he'd seen.

24. Most cells in culture grew in a single layer in a clot on a glass surface, which meant they ran out of space quickly. Increasing their numbers was labor-intensive: scientists had to repeatedly scrape the cells from one tube and split them into new ones to give them more space. HeLa cells, it turned out, weren't picky – they didn't need a glass surface in order to grow. They could grow floating in a culture medium that was constantly stirred by a magnetic device, an important technique Gey developed, now called growing in suspension. This meant that HeLa cells weren't limited by space in the same way other cells were; they could simply divide until they ran out of culture medium. The bigger the vat of medium, the more the cells grew. This discovery meant that if HeLa was susceptible to poliovirus, which not all cells were, it would solve the mass-production problem and make it possible to test the vaccine without millions of monkey cells.

25. So in April 1952, Gey and one of his colleagues from the NFIP advisory committee – William Scherer, a young postdoctoral fellow at the University of Minnesota – tried infecting Henrietta's cells with poliovirus. Within days they found that HeLa was, in fact, *more* susceptible to the virus than any cultured cells had ever been. When they realized this, they knew they'd found exactly what the NFIP was looking for.

26. When the NFIP heard the news that HeLa was susceptible to poliovirus and could grow in large quantities for little money, it immediately contracted William Scherer to oversee development of a HeLa Distribution Centre at the Tuskegee Institute.

27. At first the Tuskegee Center supplied HeLa cells only to polio-testing labs. But when it became clear that there was no risk of a HeLa shortage, they began sending the cells to any scientist interested in buying them, for ten dollars plus Air Express fees. If researchers wanted to figure out how cells behaved in a certain environment, or reacted to a specific chemical, or produced a certain protein, they turned to Henrietta's cells. They did that because, despite being cancerous, HeLa still shared many basic characteristics with normal cells: They produced proteins and communicated with one another like normal cells, they divided and generated energy, they expressed genes and regulated them, and they were susceptible to infections, which made them an optimal tool for synthesizing and studying any number of things in culture, including bacteria, hormones, proteins, and especially viruses.

28. Viruses reproduce by injecting bits of their genetic material into a living cell, essentially reprogramming the cell so it reproduces the virus instead of itself. When it came to growing viruses – as with many other things – the fact that HeLa was malignant just made it *more* useful. HeLa cells grew much faster than normal cells, and therefore produced results faster. HeLa was a workhorse: it was hardy, it was inexpensive, and it was everywhere.

"Strangest hybrid"

29. By the 1960s, scientists joked that HeLa cells were so robust that they could probably survive in sink drains or on door-knobs. They were everywhere. The general public could grow HeLa at home using instructions from a *Scientific American* do-it-yourself article, and both Russian and American scientists had managed to grow HeLa in space.

30. Henrietta's cells went up in the second satellite ever in orbit, which was launched by the Russian space program in 1960, and almost immediately afterward, NASA shot several vials of HeLa into space in the *Discoverer XVIII* satellite. Researchers knew from simulated zero-gravity studies using animals that space travel could cause cardiovascular changes, degradation of bone and muscle, and a loss of red blood cells. They also knew radiation levels were higher beyond the ozone layer. But they didn't know what effects any of this would have on humans: Would it cause cellular changes, or even cell death?

31. When the first humans went into orbit, Henrietta's cells went with them so researchers could study the effects of space travel, as well as the nutritional needs of cells in space, and how cancerous and noncancerous cells responded differently to zero gravity. What they found was disturbing: in mission after mission, noncancerous cells grew normally in orbit, but HeLa became more powerful, dividing faster with each trip.

32. In 1960, French researchers had discovered that when cells were infected with certain viruses in culture, the clumped together and sometimes fused. When they fused, the genetic material from the two cells combined, as with sperm meeting egg. The technical name for this was *somatic cell fusion*, but some researchers called it "cell sex". It was different from sperm-and-egg sex in several important ways: somatic cells were cells of the body, like skin cells, and their union produced offspring every few hours. Perhaps most important, cell sex was entirely controlled by researchers.

33. Genetically speaking, humans are terrible research subjects. We're genetically promiscuous – we mate with anyone we choose – and we don't take kindly to scientists telling us who to reproduce with. Plus, unlike plants and mice, it takes us decades to produce enough offspring to give scientists much meaningful data. Since the mid-1800s, scientists had studied genes by breeding plants and animals in specific ways – a smooth pea with a wrinkled one, a brown mouse with a white one – then breeding their offspring to see how genetic traits passed from one generation to the next. But they couldn't study human genetics the same way. Cell sex solved that problem, because it meant researchers could combine cells with any traits they wanted and study how those traits were passed along.

34. In 1965 two British scientists, Henry Harris and John Watkins, took cell sex an important step further. They fused HeLa cells with mouse cells and created the first human-animal hybrids – cells that contained equal amounts of DNA from Henrietta and a mouse. By doing this, they helped make it possible to study what genes do, and how they work.

35. In addition to the HeLa-mouse hybrid, Harris fused HeLa with chicken cells that had lost their ability to reproduce. His hunch was that when those deactivated chicken cells fused with HeLa, something inside HeLa would essentially turn the chicken cell back on. He was right. He didn't know how it worked yet, but his discovery showed that something in cells regulated genes. And if scientists could figure out how to turn disease genes off, they might be able to create a form of gene therapy.

36. Soon after Harris's HeLa-chicken study, a pair of researchers at New York University discovered that human-mouse hybrids lost their human chromosomes over time, leaving only the mouse chromosomes. This allowed scientists to begin mapping human genes to specific chromosomes by tracking the order in which genetic traits vanished. If a chromosome disappeared and production of a certain enzyme stopped, researchers knew the gene for that enzyme must be on the most recently vanished chromosome.

37. Scientists in laboratories throughout North America and Europe began fusing cells and using them to map genetic traits to specific chromosomes, creating a precursor to the human genome map we have today. They used hybrids to create the first monoclonal antibodies, special proteins later used to create cancer therapies like Herceptin, and to identify the blood groups that increased the safety of transfusions. They also used them to study the role of immunity in organ transplantation. Hybrids proved it was possible for DNA from two unrelated individuals, even of different species, to survive together *inside* cells without one rejecting the other, which meant the mechanism for rejecting transplanted organs had to be *outside* cells.

38. Scientists were ecstatic about hybrids, but throughout the United States and Britain, the public panicked as the media published one sensational headline after the next:

MAN–ANIMAL CELLS ARE BRED IN LAB…
THE NEXT STEP COULD BE TREE MEN…
SCIENTISTS CREATE MONSTERS

39. *The Times* of London called the HeLa-mouse cells the "strangest hybrid form of life ever seen in the lab – or out of it." A *Washington Post* editorial said, "We cannot afford any artificially induced mouse-men." It called the research "horrendous" and said the researchers should leave humans alone and "go back to their yeasts and fungi." One article ran with an image of a half-human, half-mouse creature with a long, scaly tail; another ran with a cartoon of a hippopotamus-woman reading the newspaper at a bus stop. The British press called the HeLa hybrids an "assault on life," and portrayed Harris as a mad scientist. And Harris didn't help the situation: he caused near-pandemonium when he appeared in a BBC documentary saying that the eggs of man and ape could now be joined to create a "mape."

40. Harris and Watkins wrote letters to editors complaining they'd been quoted out of context, their story sensationalized to "distort, misrepresent and terrify." They assured the public that they were just creating cells, not "trying to produce centaurs." But it didn't help. A public survey about their research was overwhelmingly negative, calling it pointless and dangerous, an example of "men trying to be gods." And the PR problem for cell culture was only going to get worse from there.

The secret of immortality

41. More than thirty years after Henrietta's death, research on HeLa cells finally helped uncover how her cancer started and why her cells never died. In 1984 a German virologist named Harald zur Hausen discovered a new strain of a sexually transmitted virus called Human Papilloma Virus 18 (HPV-18). He believed it and HPV-16, which he'd discovered a year earlier, caused cervical cancer. HeLa cells in his lab tested positive for the HPV-18 strain, but zur Hausen requested a sample of Henrietta's original biopsy, so he could be sure her cells hadn't been contaminated with the virus in culture. The sample didn't just test positive; it showed that Henrietta had been infected with multiple copies of HPV-18, which turned out to be one of the most virulent strains of the virus.

42. There are more than one hundred strains of HPV in existence, thirteen of which cause cervical, anal, oral, and penile cancer – today, around 90 percent of all sexually active adults become infected with at least one strain during their lifetimes. Throughout the eighties, using HeLa and other cells, scientists studied HPV infection and how it causes cancer. They learned that HPV inserts its DNA into the DNA of the host cell, where it produces proteins that lead to cancer. They also found that when they blocked the HPV DNA, cervical cancer cells stopped being cancerous. These discoveries would help lead to an HPV vaccine, and eventually earn zur Hausen a Nobel Prize.

43. Research into HPV eventually uncovered how Henrietta's cancer started: HPV inserted its DNA into the long arm of her eleventh chromosome and essentially turned off her p53 tumor suppressor gene. What scientists still haven't figured out is why this produced such monstrously virulent cells both in and out of Henrietta's body, especially since cervical cancer cells are some of the hardest of all cells to culture.

44. When I talked to Howard Jones fifty years after he found the tumor on Henrietta's cervix, he was in his early nineties and had seen thousands of cervical cancer cases. But when I asked if he remembered Henrietta, he laughed. "I could never forget that tumor," he said, "because it was unlike anything I've ever seen."

45. I talked to many scientists about HeLa, and none could explain why Henrietta's cells grew so powerfully when many others didn't even survive. Today it's possible for scientists to immortalize cells by exposing them to certain viruses or chemicals, but very few cells have become immortal on their own as Henrietta's did.

46. Every decade has had its landmark moments in HeLa research, and the connection between HPV and cervical cancer was only one of several in the eighties. At the beginning of the AIDS epidemic, a group of researchers – including a molecular biologist named Richard Axel, who would go on to win a Nobel Prize – infected HeLa cells with HIV. Normally, HIV can infect only blood cells, but Axel had inserted a specific DNA sequence from a blood cell into HeLa cells, which made it possible for HIV to infect them as well. This allowed scientists to determine what was required for HIV to infect a cell – an important step toward understanding the virus, and potentially stopping it.

47. Axel's research caught the attention of Jeremy Rifkin, an author and activist who was deeply involved in a growing public debate over whether scientists should alter DNA. Rifkin and many others believed that any manipulation of DNA, even in a controlled laboratory setting, was dangerous because it might lead to genetic mutations and make it possible to engineer "designer babies." Since there were no laws limiting genetic engineering, Rifkin regularly sued to stop it using any existing laws that might apply.

48. In 1987 he filed a lawsuit in federal court to halt Axel's research on the grounds that it violated the 1975 National Environmental Policy Act, because it had never been proven environmentally safe. It was widely known, Rifkin pointed out, that HeLa was "an extraordinarily virulent and infectious line of cells" that could contaminate other cultures. Once Axel infected HeLa cells with HIV, Rifkin said, they could infect other cells and expose lab researchers around the world to HIV, "thus increasing the virus' host range and potentially leading to the further hazardous dissemination of the AIDS virus genome."

49. Axel responded to the suit by explaining that cells couldn't grow outside of tissue culture and that there was a world of difference between culture contamination and HIV infection. *Science* reported on the lawsuit, writing, "Even Rifkin admits that taken together these events sound more like the plot of a grade-B horror movie than the normal run of affairs in the country's biomedical research laboratories." Eventually the suit was dismissed, Axel went on using HeLa for HIV research, and Rifkin's horror-film scenario didn't come true.

50. But in the meantime two scientists had developed a theory about HeLa that sounded far more like science fiction than anything Rifkin had come up with: HeLa, they said, was no longer human.

51. Cells change while growing in culture, just as they change in a human body. They're exposed to chemicals, sunlight, and different environments, all of which can cause DNA changes. Then they pass those changes on to each new generation of cells through cell division, a random process that produces even more changes. Like humans, they evolve.

52. All of this happened to Henrietta's cells once they were placed in culture. And they passed those changes on to their daughter cells, creating new families of HeLa cells that differed from one another in the same way that second, third, and fourth cousins differ, though they share a common ancestor.

53. By the early nineties, the little sample of Henrietta's cervix that Mary had put into culture in the Gey lab had given rise to many tons of other cells – all still known as HeLa, but all slightly different from one another, and from Henrietta. Because of this, Leigh Van Valen, an evolutionary biologist at the University of Chicago, wrote, "We here propose, in all seriousness, that [HeLa cells] have become a separate species."

54. Van Valen explained this idea years later, saying, "HeLa cells are evolving separately from humans, and having a separate evolution is really what a species is all about." Since the species name *Hela* was already taken by a type of crab, the researchers proposed that the new HeLa cell species should be called *Helacyton gartleri,* which combined *HeLa* with *cyton*, which is Greek for "cell," and *gartleri*, in honor of Stanley Gartler, who'd dropped the "HeLa Bomb" twenty-five years earlier.

55. No one challenged this idea, but no one acted on it either, so Henrietta's cells remained classified as human. But even today some scientists argue that it's factually incorrect to say that HeLa cells are related to Henrietta, since their DNA is no longer genetically identical to hers.

56. Robert Stevenson, one of the researchers who devoted much of his career to straightening out the HeLa contamination mess, laughed when he heard that argument. "It's just ridiculous," he told me. "Scientists don't like to think of HeLa cells as being little bits of Henrietta because it's much easier to do science when you disassociate your materials from the people they come from. But if you could get a sample from Henrietta's body today and do DNA fingerprinting on it, her DNA would match the DNA in HeLa cells."

57. Around the time Van Valen suggested HeLa was no longer human, researchers began exploring whether Henrietta's cells might hold the key to human life extension – perhaps even immortality – and headlines once again claimed that scientists had found the fountain of youth.

58. In the early 1900s, Carrel's chicken-heart cells supposedly proved that all cells had the potential for immortality. But *normal* human cells – either in culture or in the human body – can't grow indefinitely like cancer cells. They divide only a finite number of times, then stop growing and begin to die. The number of times they can divide is a specific number called the Hayflick Limit, after Leonard Hayflick, who'd published a paper in 1961 showing that normal cells reach their limit when they've doubled about fifty times.

59. After years of disbelief and argument from other scientists, Hayflick's paper on cell limits became one of the most widely cited in his field. It was an epiphany: scientists had been trying for decades to grow immortal cell lines using normal cells instead of malignant ones, but it had never worked. They thought that their technique was the problem, when in fact it was simply that the lifespan of normal cells was preprogrammed. Only cells that had been transformed by a virus or a genetic mutation had the potential to become immortal.

60. Scientists knew from studying HeLa that cancer cells could divide indefinitely, and they'd speculated for years about whether cancer was caused by an error in the mechanism that made cells die when they reached their Hayflick Limit. They also knew that there was a string of DNA at the end of each chromosome called a *telomere*, which shortened a tiny bit each time a cell divided, like time ticking off a clock. As normal cells go through life, their telomeres shorten with each division until they're almost gone. Then they stop dividing and begin to die. This process correlates with the age of a person: the older we are, the shorter our telomeres, and the fewer times our cells have left to divide before they die.

61. By the early nineties, a scientist at Yale had used HeLa to discover that human cancer cells contain an enzyme called *telomerase* that rebuilds their telomeres. The presence of telomerase meant cells could keep regenerating their telomeres indefinitely. This explained the mechanics of HeLa's immortality: telomerase constantly rewound the ticking clock at the end of Henrietta's chromosomes so they never grew old and never died. It was this immortality, and the strength with which Henrietta's cells grew, that made it possible for HeLa to take over so many other cultures – they simply outlived and outgrew any other cells they encountered.