EINSTEIN'S ENIGMA
or
Black Holes in My Bubble Bath

C. V. Vishveshwara

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To the memory of my parents

My father C. K. Venkata Ramayya
Writer, scholar, orator
And
My mother K. Venkatasubbamma
Who supported my father and took care of us all

CONTENTS

Chapter 1

THE BATHTUB

I love my bathtub. To all appearances, there is nothing special about it except that it is rather small. It is an old fashioned bathtub made of enamelled metal, discoloured at several places with spidery patterns showing up where the enamel has cracked. But, there is magic in my bathtub. It has strange, unusual powers. I shall tell you all about it in good time, if you will bear with me. First let me recount how I came to acquire this treasure of mine, which was an extraordinary event in itself.

It happened a few days ago. I woke up late and lazed around having worked all through the previous night. What kind of work do I do? You may ask. Well, I am a FLOP, a Free Lance Organiser of Proposals, that is. You would be surprised at the number of people who find it hard to write up projects and proposals that enable them to sell their ideas. I help them. For a fee of course! I arrange facts and figures, make up charts and tables, generate graphs and diagrams, and tie up the whole caboodle in pink ribbon ready for consumption. I am the systematiser of the disorganised and the voice of the inarticulate. Do you have a proposal for a genetically engineered purple cow with green spots that gives claret instead of milk and lays dinosaur eggs? No problem. By the time I am done with it, any funding agency would be eating out of the cow's hoofs. As a matter of fact, on the night before the fateful day, I was working on a patent application for a high-tech toothbrush. The computerised handle of the toothbrush contains toothpaste that is released in accurately measured, minute quantities. The bristles are the sensors of a miniature ultra-sound seismograph that scans the cavities and generates colour-coded pictures on the back of the brush head, which serves as a video screen. The data are transmitted to the user's dentist by e-mail, fax, and telepathy. The treatment can be received instantaneously, if it is in the action-at-a-distance form like *Reiki*, which invokes the universal life-force. Does this gadget work? What does it matter?

It is ideas that rule the world, even if they do not work. The toothbrush idea worked for me all right, since I had collected my fee in advance.

To continue. On the day that I consider to be the most important one in my life, I shaved, showered and got ready to go out. I live on the third floor of an old apartment building. The roof-terrace above me is, by arrangement with my landlord, exclusively my domain. There I can do whatever I please. If I so wished, I could freely sun bathe in the nude, stargaze with the naked eye or just let the fog swirl around me. Graduate students, who study in the nearby university, occupy apartments other than mine. Descending the stairs is like making a culinary tour around the world. A sensitive olfactory analysis of the smells emanating from different apartments would reveal the cuisine of various nationalities. Such as the Chinese, Indian, Spanish and so on, all characterised by the spices of the respective regions, like ajinomoto, asafoetida, and aceite de oliva virge. I am unable to identify the smell coming out of one particular apartment. For all I know, a bunch of students from the Arctic may be living in that apartment, frying algae in whale fat for their food. The ground floor is filled with the fragrance of various perfumes. Some girls live there. Probably, they never cook, managing to subsist on – dates.

As I walked down from my apartment house to the street corner, Fernando and his wife Maria, who own a small store that sells groceries and household goods, greeted me. When they are not busy, Fernando and Maria relax on the sidewalk in their lounge chairs outside their store, often sipping beer or wine and chatting away. Their eleven-year old daughter Falicia keeps a menagerie of animals – a cat, a rabbit, a turtle, and small animals of different kinds. I am expected to say hello to at least one of them whenever I meet Falicia. This time it was Macho the turtle. The turtle lifted one eyelid, looked at me dolefully and made a sound that resembled a deep sigh. 'Off to Bruno's as usual, *Señor* Alfie?' called out Fernando. Ah, that is my name, Alfie for Alfonso L. Sabio. I nodded, smiled and moved on.

Bruno's, as it is popularly known, is *Benvenuto* the cosy little Italian restaurant. Bruno Beltrametti is its owner, chef, and the headwaiter all rolled into one. The tables are neatly arranged, covered with beige tablecloths embellished with intricate designs in maroon. Placed on each of them is a cylindrical flower vase made of solid Venetian glass accommodating a single flower. Bruno plays soothing classical and folk music in the background and sometimes, if persuaded, sings arias from his favourite operas. Most importantly, he supplies stacks of paper napkins that are freely used by the university people who frequent the restaurant. Physicists write formulas on them, biologists doodle

molecular structures, artists make sketches, while mathematicians just twist them around as they think their abstract mathematical thoughts – or at least that is what they claim.

As I munched on the toasted cheese that came with my pasta and sipped my second glass of Bruno's delicate wine, in walked George Gallagher. Blew in like a whirlwind I should say. George works in theoretical astrophysics. He is one of the university people I have met at Bruno's. Over the years, a close and warm friendship has grown between the two of us.

George slumped into the chair next to mine and ordered a Sicilian and a large beer. A Sicilian, if you have never tried it, is a small, thick, square pizza. According to George, his colleagues at the university are fond of Sicilians, because, like the dish, they are all square and thick even though they claim to be liberal intellectuals. Of course George is an exception. Bruno dislikes the Sicilian immensely. 'What can I do, I have to make a living, no? So I prepare it,' he says. Probably no one in Sicily has ever heard of this dish. If you insisted that it originated in Sicily, the *Cosa Nostra* might rub you out.

'Oh, Alfie my boy, I am tired, tired, tired,' sighed George as he took a big gulp of his beer. 'It is all because of old Albert Einstein you know.'

'Why, what has he done to you now?'

'You see, in 1905, sitting in his patent office in Berne, he did wonders. He explained Brownian motion, the feverish motion of molecules in a liquid. He explained the photoelectric effect, electrons streaming out of some metals when light was shone on them. He gave the world his special theory of relativity. Which completely changed the way we look at nature. Space and time became relative quantities. So did mass. It was a revolution. Drum rolls, cannons firing, the whole works. Bam, bam! That was good enough. Did Einstein stop there? No, the old fox goes on and formulates his general theory of relativity. A brand new theory of gravitation totally different from that of good old Isaac Newton. What happens? The new theory predicts all sorts of crazy things like black holes, gravitational radiation, the expanding universe and what not. And I have to deal with all this in my old age. Bruno, another Sicilian and a large beer please. And Bruno, please stop grimacing like that. It takes away my appetite.'

'Go on George,' I patted his hand. 'Pour it all out: I shall drown your sorrows in alcohol for you.'

'All right, once we theoreticians could dream up things unhampered by reality. Reality, my friend, is a redundant nuisance if you ask me. But now, observations have caught up with us. We have to account for all sorts of bizarre things happening up there in the sky. Just yesterday, we learnt about some ex-

traordinary phenomenon occurring in our own galaxy. I think two binary systems, each containing a black hole, are merging together. Dealing with just one black hole, swallowing up matter and energy is difficult. Two make it extremely hard. But handling two binaries each containing a black hole! Heaven help me, it is almost impossible. We shall crack it anyway. Alfie, you don't look too happy. What is the matter, my boy?'

'Let me confess. I feel a bit uncomfortable with all this black-hole talk.'

'Why? Black holes are beautiful you know!'

'I don't doubt that. But, I hear all these words – black holes, binaries, mergers and what not. You'll have to explain everything to me from scratch, George, so I am able to understand what is going on. Then I can really appreciate your problems.'

'Fair enough. All right, next time we meet I'll begin my private lessons tailored to suit you. Provided the drinks are on you,' said George. And then he added, 'Seriously, Alfie, would you like me to talk to you for an hour or so and give you just an overview of black holes? Or should we have several sessions so I can deal with the subject in some detail complete with all the background material and do justice to it? The choice is yours.'

'No doubt about it, George, let us meet as many times as you wish. I'm ready for a detailed exposition. Would you be using mathematics though? Not that I am afraid of it.'

'Very well then, I'll write down some very simple mathematical expressions, which even a high-school kid can understand. That makes things much more precise, you know. Of course, they are not absolutely essential for understanding black-hole physics. But, they would help. And we can draw enough diagrams to illustrate whatever we discuss. What do you say?'

'Sounds great,' I said enthusiastically.

'I have to rush now, Alfie. My students are running a monstrous computer programme. And I have to be there all night to give them moral support.'

'In other words: To breathe down their necks. George, don't be too hard on those poor boys.'

'Two boys and one girl to be precise. I will be no harder on them than on myself, I promise. Bye, Alfie. Ciao, Bruno.'

George swept out like a tornado. All this heady talk and the somewhat generous consumption of wine had made me a bit tipsy. I wished Bruno good night and started on my homeward journey.

Just before reaching the street on which I live, there is a blind alley. Along the short stretch of this passageway there are a few empty derelict buildings and a

couple of warehouses. There are no streetlights. At night it is dark and dismal here. But that night, there seemed to be some signs of life within one of the buildings. A diffuse shaft of light emerged from one of the windows and dissipated itself in the surrounding fog. This was a bit surprising, because this building has been sealed off for quite some time now. Even more intriguing was the fact that there was a sign above the door, which read *Al's All-in-One Store*. There were several other signs as well listing an assortment of items available within and a big one announcing *Bathtubs for Half Price*! I had never noticed any of this before. Quite curious about this new place, I pushed open the door, which happened to be unlocked, and entered.

The place was crammed with a chaotic variety of merchandise. There was no one in sight. Rather suddenly and instinctively, I felt a presence close to me. Sure enough, a man had appeared at my elbow, presumably the storekeeper. I was riveted by his eyes looking straight at me. Eyes that were gentle and kind, yet with a mischievous twinkle in them. Time had etched a network of lines on his calm face framed by a halo of white hair.

'I am Al, at your service,' he said with a warm, friendly smile. 'So you have come for your bathtub, *ja*?'

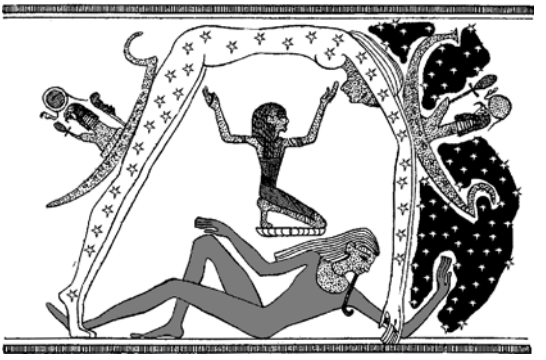
He spoke softly but with a thick accent. I could not place it. German? Swiss? Or perhaps it was one of those accents that belonged everywhere and nowhere.

I had entered the place with no intention of buying anything whatsoever. But this stranger had assumed that I had come to buy a bathtub of all things. Before I could even think about this turn of events, Al spoke up.

'*Wunderbar!* Follow me please, if you will, *mein lieber Herr*.' He gestured with his head, his long, unruly hair waving in the air, to show me the way. He had a quiet way of walking almost like a slow dance movement.

As Al led the way, the room seemed to expand and turn into a large gallery that held an assortment of bathtubs of different sizes, shapes and colours.

'Ah, you are surprised,' said Al with amusement. 'Yes, we have a magnificent collection of bathtubs. Many of them have great historical value. Obviously, they are not for sale. Here, let me show you some of them. Look at this one. It comes from ancient Egypt. Belonged to some queen or the other they say. Nefertiti perhaps. Maybe Cleopatra. Let's assume it was once Cleopatra's since she is better known. Legend and fantasy are as important as reality, sir. Or possibly more. But look at it. Is it just a bathtub? No, sir, it is a magnificent piece of art! What is more, its design and decoration reflect the cosmic order that the ancient Egyptians once believed in.



According to the Egyptian cosmic myth, Al went on to explain, the sky goddess Nut, decked with shining stars, arches over her reclining husband Seb, the earth god, while their offspring Shu, who controls the winds, kneels between them. The sun, in the form of Amon-Ra, god of gods, sails in his divine barge along Nut's body. Each night he dies and enters Amenti, the nether world, to be broken up and scattered in a thousand sparks that turn into the stars. At dawn he is reborn to repeat the perpetual cycle of birth and death.

The bathtub, shaped like the sun's barge, was enormous. It was made of black marble covered with innumerable semiprecious stones of different kinds. One half of it was inlaid with flakes of turquoise and lapis lazuli to simulate the blue sky. In the middle was the brilliant sun fashioned out of a mixture of gold and silver. The blue sky turned gradually into yellow and red twilight created by shimmering pieces of amber and garnet. Finally the night sky was depicted by the dark background of black marble itself studded with a variety of sparkling white stones including a spray of small diamonds. An opal moon shone with a soft glow. The effect, to say the least, was stunning. This bathtub, which was supposed to have belonged to Cleopatra long ago, reminded me of her barge as described by Shakespeare:

The barge she sat in, like a burnish'd throne,
Burn'd on the water; the poop was beaten gold,
Purple the sails, and so perfumed, that
The winds were love-sick with them; the oars were silver,
Which to the tune of flutes kept stroke, and made
The water which they beat to follow faster,
As amorous of their strokes. For her own person,
It beggar'd all description.

Lovely, don't you agree? At this point, I must warn you of my phenomenal memory for anything and everything I read. I can reel off short quotations, recite long passages and supply you with an abundance of unbelievable trivia at the drop of a hat. And I often make good use of my rare gift, as you will see. But let me continue with my story.

'Here is my favourite one, *mein lieber Herr*,' said Al as he patted the next bathtub. It had been carved out of white marble, simple and elegant, in the shape of a perfect ellipse. On one side was engraved the picture of a pole balanced on a conical peg, while on the other there was a spiral.

'The owner of the bathtub discovered the spiral you see engraved on it. He claimed that, if he were to be given a long enough lever and a place to stand in space, he could move the earth,' Al said. And then he jubilantly announced, 'His name was Archimedes'

'From this very bathtub', Al continued after pausing dramatically for a moment, 'Archimedes ran down the street, stark naked, shouting '*Eureka*'. Imagine our scientists following his example in their great haste to publish their results! What a sight it would be!' Al bellowed with laughter, tears in his eyes. The contrast between his soft speech and his ringing laughter, which echoed from wall to wall, was enormous. I was totally unprepared for this roaring, booming, friendly, all-enveloping laughter.

Al's expression turned serious as he led me to the third bathtub. It was in the shape of a crude rectangular box and the material used was humble sandstone, chipped at many places. It was unadorned and looked more like a coffin rather than a bathtub. Lying inside was a badly decayed plank smudged with patches of black.

'Here is a gory one that was much used by its former owner Jean Paul Marat, one of the leaders of the French Revolution. As the story goes, he had contracted some horrible skin ailment when he was hiding in the sewers of Paris and had to soak himself constantly in lukewarm medicated water. He used that plank lying there for writing. A woman named Charlotte Corday stabbed him to death during one of his soaking sessions. What a way to go! You must have seen the painting entitled *Marat*, by the French artist Jacques Louis Da-

vid, depicting Marat's death. I am told that, if you look carefully, you may still discover some faint bloodstains in this bathtub. Gives you the creeps.' Al seemed to shiver at the thought. 'Well, there are many other historical specimens. But let us take a look at the one you have come for. Pardon me, the small black box over there is not a bathtub. It is my violin case,' Al roared with laughter.

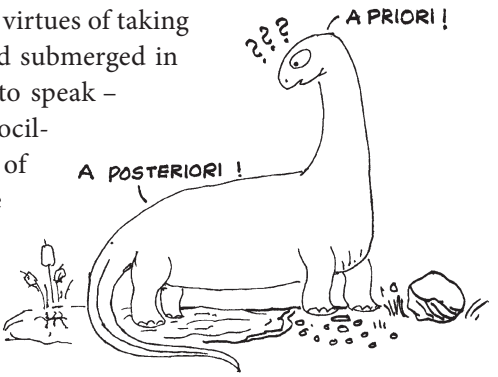
'As you know, sir,' continued Al, filling his pipe and lighting it as he led the way. 'Taking a bath is an extremely important part of one's life. Could anything else offer the blissful state of prenatal insouciance as when you lie soaking yourself in warm water, eyes closed and preferably sucking your thumb? Throw in some bath salts containing special ingredients including specific metals. Then millions of molecules in frenzied Brownian motion will massage your muscles and photoelectrons will stimulate your cells. Time will stand still. Somebody should take out a patent on this invention, the Brownian Photoelectric Bathtub. What do you think?'

Momentarily, his eyes became distant and dreamy as though he had been transported to another place, another time. 'Patents, Brownian motion, photoelectrons, time slowing down. Oh yes, those were the days!' he whispered to himself. Returning from his reverie, he went on, 'Where were we? Oh yes, the virtues of taking a bath. You know, sir, a whole species could be wiped out for the lack of bathing. Take for instance the dinosaurs. I vaguely remember a verse written in the early nineteen hundreds that described dinosaurs and their two brains. That verse I think is quite relevant to what we are talking about. I am sure you must have read it too.'

As a matter of fact, I had read the poem Al had in mind. One Bert Taylor of the *Chicago Tribune* had written it in 1912. I had long forgotten it, but my unfailing memory brought it back to my mind. The lines about the dinosaur's purported two brains are as follows:

The creature had two sets of brains.
One in his head, the usual place,
The other in his spinal base.
So that he could reason a priori,
As well as a posteriori.

The entire poem is quite interesting. I hope you will read it some time. For the moment, let me go on with what Al was telling me.



Al went on with his discourse on the virtues of taking a bath. 'As long as the dinosaurs stayed submerged in water – taking long, healthy baths so to speak – the bottom brain was kept lulled into docility. But when the dinosaurs crawled out of water and became land animals, the lower brain started competing with the upper one. *A priori* and *a posteriori* got mixed up and the species became extinct. Humans do not have this problem mercifully, since they are not equipped with a brain at the base of their spines, although many behave as if they did. Well, I am told that modern findings do not support the hypothesis that the dinosaurs had two brains. What a pity, a beautiful hypothesis dashed against the hard rock of fact. Anyway, allow me to let you in on a secret. Personally, I hate baths myself. That follows in the tradition of the great Kepler who bathed only once in his entire lifetime. That too was at the insistence of his wife and against his own better judgement. It nearly killed him. So, I try to avoid taking a bath although I extol its virtues. As you very well know, sir, there is nothing nobler than to preach what one does not practice.'

Al bent down to tie his shoelace. His shoes were scuffed and he wore no socks beneath his rumpled trousers. Straightening up as he smoothened the sweatshirt he was wearing, he exclaimed, 'Ah, now for your bathtub!' With a flourish, Al pulled off the tattered cloth that covered the bathtub. I could not believe my eyes. This bathtub, as he called it, was nothing more than a kitchen sink! How could anyone but a midget get into it was beyond my comprehension.

'You are obviously surprised at the modest dimensions of the bathtub. Half price, half size!' laughed Al. 'But take my word for it. You will find no difficulty in getting into your bathtub. What is more important is the fact that the bathtub is a magical one. It is filled with myth, math, science, philosophy, art, literature, and above all dreams; not to mention your bath water.

The so-called bathtub came with a kit on which was written *Five Easy Steps to Install Your Bathtub*.

'Oh, yes, it is child's play to install your bathtub,' said Al. 'I am going to wrap it up in brown paper, and tie it with string. There you are, all yours.'

There was a problem though. Old-fashioned kitchen sinks, like this one, could be quite heavy. How was I going to carry it home?

'How are you going to carry it?' Al seemed to read my mind. 'Not to worry! We will have it delivered to your doorstep in no time. Oh, I almost forgot. Along with the bathtub, you get a free sample of our special bubble-bath additive.'

He produced a plastic bag filled with perfectly spherical black beads. They were black in a peculiar manner, reflecting no light at all, but quite pretty in a way. He walked me to the door and held it open for me.

'Rest assured that your newly acquired possession will give you wondrous moments you could never have imagined. Goodbye now,' said Al. As I watched him, I wondered whether I had met him before. No, no, that was impossible. Did he closely resemble someone whose description I had read before? My mind seemed to have become fuzzy and I was confused. I caught myself meandering through the maze of my memories as I realized that Al was regarding me with a mysterious, knowing smile. As I was about to leave, Al said gently, 'We shall meet again soon enough, my friend.'

Slowly I started walking home. Before turning the corner, I looked back. The alley was plunged in darkness and there was no longer any light in the shop. Had I been dreaming? The shop, the shopkeeper and everything that had happened, was it all my imagination? The whole episode was a bit scary.

Fernando and Maria were still in their lounge chairs. They had closed their shop and were having a beer before retiring.

'Want to have a sip with us, *Señor* Alfie?' Fernando asked.

'Thanks Fernando. Some other time. I am a little tired.'

'Tired? You look more like, let me see, dazed I would say. What have you been up to, *Señor* Alfie?' Fernando grinned slyly.

'Oh, I have been browsing around a bit in this quaint little store I found. That's all, Fernando,' I replied.

'What store is that?'

'*Al's All-in-One Store*. You must know it.'

'Never heard of it. Where is it?'

'At the beginning of the blind alley behind our street. Second shop on the right you know.'

'Are you sure? There's no such shop. I was there just this afternoon. That place has been boarded up for long time now. Well, what more can I say?' Fernando looked at me searchingly. But before Fernando could fire off more questions, I said good night to the two of them, who seemed to be quite curious, and left.

I trudged up the stairs to my apartment, tired and confused. Once again I wondered whether I had imagined the whole thing about Al and his store. I stopped short at the door of my apartment. There it was! Neatly arranged in front of my door was the big package wrapped in brown paper, tied around with string. I was stupefied. My bathtub delivered to my doorstep as Al had promised! I quickly unlocked the door and carried the bathtub inside. Surprisingly, it felt quite light. I went straight into my bathroom and fixed the little bathtub in five easy steps as instructed by the accompanying kit. The magic moment had arrived. I filled it with hot water, stirred in half a spoonful of the bubble bath mixture and gingerly got in. To my amazement, I was able to fit into the bathtub quite comfortably. Had the bathtub expanded? Had I shrunk? It mattered little. The bubble bath was unbelievably soothing. Not just physically. The vapours rising from the bath water seemed to seep into my mind and turn it into a soft, smooth fluid in which thoughts, imagination, and awareness of the external world mingled in a flowing stream. Countless bubbles surrounded me now. Transparent, multicoloured spheres that glistened and trembled. Within each bubble, I could see a dark speck, once again a minute, perfect sphere. Each black speck appeared to grow a little, as it absorbed the vapour in its immediate vicinity. Here and there, bubbles would combine and become one, while the black specks too coalesced. As they did, they seemed to become warmer. Some bubbles burst when the black specks within them evaporated and disappeared. Slowly, words I had heard in the evening came to my mind. Black holes, swallowing up matter and energy, merging together! Was this happening in my own bathtub? Or was I imagining things yet again?

The bubbles were swirling all around me massaging my body. There was a large concentration of them near my feet. They were gently tugging at me. As I luxuriated in this fantastic bubble bath, my eyes grew heavy and I drifted into a supremely blissful slumber.

Chapter 2

THE STELLAR BED

When I entered Bruno's, I saw that George was already there, waiting for me at our favourite table. George is in his fifties, thickset but not fat, with an incipient paunch, hair turning grey and thinning. Beneath his bushy eyebrows, he wears thick-rimmed glasses that keep sliding down his nose, requiring him to keep pushing them up constantly. Invariably he wears a jacket, not for the sake of appearance he says, but to stuff the pockets with important papers - each pocket reserved for a particular type of document. In other words, his jacket is his mobile filing cabinet. All in all, George looks quite distinguished and can easily pass for a professor, which he is.

'Bruno,' George called out after greeting me warmly. 'Let us have your most expensive wine, please. Alfie is going to pay for it. Fee for the lessons I will be giving him.'

'I don't know about expensive wine,' replied Bruno. 'But I got some excellent wine straight from Frascati. Something they supply to the Italian President himself. No labels. Want to try?'

'Do you have to ask, Bruno? What do we eat?'

'What you eat must match what you drink,' Bruno said solemnly. 'Just like what you drink must match what you eat. It is like happy marriage.'

'And the consummation lies in its consumption. Right, Bruno?' I added.

'So, I make you my special Zuppa Marinara. My own recipe. Not on the menu.'

'Oh, no, Bruno,' protested George. 'I am not in a mood for any fish soup.'

'My Zuppa is not your watery soup, you know,' Bruno explained patiently. 'It is fresh shellfish cooked in sauce of Marsala wine. Served on a bed of thick bread soaking up the sauce slowly. A side dish of pasta with herbs. *Perfetto*!'

'Bruno, the Greeks said that one of their ideals was a sound mind in a sound body,' I commented. 'But you are giving us sound minds in round bodies!'

'What do I know about the Greeks? I am from a Latin country,' Bruno shrugged.

'Actually, Bruno, the person who mentions this ideal was not a Greek at all,' I explained. 'He was a Roman, so your countryman, you see. He was the satirical poet Juvenal, who lived in the second century AD. And he wrote in Latin, *mens sana in corpore sano*, a sound mind in a sound body. But you give us *mens sana in corpore rotundo*, a sound mind in a round body!'

Bruno shook his head, looking at me as if I had gone completely out of my mind and walked away.

'Come to think of it, Alfie, the Greeks' ideal of roundness went a long way,' remarked George. 'That concept entered their astronomy too, you know. Circle and sphere, the perfect figures in two and three dimensions. That is why for centuries the orbits of the planets were assumed to be circles until Kepler showed that they were ellipses.'

'Let me add a bit more to this roundness business, George,' I offered. 'You know what Xenophanes, in the Sixth Century BC, thought? He claimed that God, being perfect, had to be spherical in shape! According to Aristotle, Xenophanes wrote that the *universal homogeneity of God implies that he has the shape of a sphere. And because he is uniformly the same and round as a ball, thus he is neither limited nor unlimited, neither in rest nor in motion*. But some people made fun of this notion, you know. They parodied the word *apotheosis* or deification as *apokolokinthiosis* or pumpkinification! The two Greek words sound somewhat similar, don't they?'

'Obesity is close to divinity then,' George chuckled.

'Indeed. Let us eat and get fat,' I said.

'Well, let us forget the spherical God for a moment,' George said. 'Lots of things in nature are spherical in shape though. Take, for instance, the Solar System. The Earth is almost spherical. So are the planets. There is always some flattening due to rotation, of course. As a matter of fact, the Sun is spherical too.'

The wine had arrived. I took a sip. It was exquisite, mellow with a hint of the grapes that had undergone this unearthly transformation. George sighed with pleasure. He pulled out a paper napkin and started sketching as he described the anatomy of the Sun.

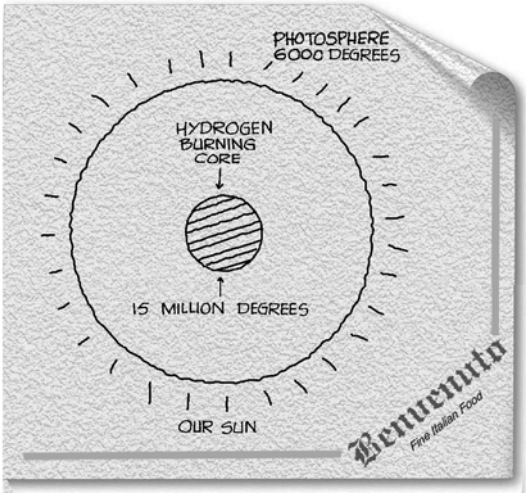
'Let me continue. The Sun is a huge ball of fire, a sphere of burning gas,' George went on. 'It is seventy-five per cent hydrogen, about twenty-four per cent he-

lium and a small quantity of other elements. What we see of the Sun is the light from the surface, which is at a temperature of about six thousand degrees. By the way, in astronomy we always use the Kelvin scale for the temperature. I am sure you know what it is, Alfie.'

'Oh, yes. You take the centigrade or the Celsius scale, which consists of equal degrees between zero, fixed at the melting point of ice, and one hundred, fixed at the boiling point of water, at a pressure of seven hundred and sixty millimetres of mercury. To get the Kelvin scale, you add two hundred and seventy-three degrees to the Celsius temperature. So, zero on the Kelvin scale corresponds to minus two hundred and seventy-three degrees Celsius. This is known as the absolute zero temperature. How about that?'

'Amazingly accurate, Alfie,' George chuckled.

'All right, coming back to the Sun, the energy actually comes from the centre, doesn't it?'



'Exactly. Most of the mass of the Sun is concentrated around the centre, nearly ninety per cent within the inner half of its radius. The temperature at the centre is some fifteen million degrees. Horribly hot, wouldn't you say?'

'Right, an inferno too hot for even Satan.'

'The pressure is about a hundred billion times that of the Earth's atmosphere. And the density is around twelve times that of lead.'

'Are you saying that the Sun has a solid core or what?'

'Did I say that? No, sir. The temperature is so high that the electrons are ripped off the atoms. They fly around madly, leaving the nuclei shamelessly naked. The nuclei themselves streak around at a frenetic pace and come close to one another. The density and pressure are extraordinarily high. But this violently agitated mixture still behaves like a gas, you know. So, the core is not solid at all. This is the nuclear furnace where the Sun's energy is generated. We shall talk about the nuclear processes taking place here a little later. All this talk of a hot core has made me thirsty.'

George took a couple of sips and continued.

'The energy is created in the form of high-energy X-rays, or gamma rays as they are called. As this radiation travels towards the surface it is continually scattered by the matter in the Sun's interior. As a result, it keeps losing energy as it travels and becomes the visible radiation streaming out of the Sun. Can you guess how long it takes for the radiation to travel from the centre of the Sun to its surface?'

'Let me estimate rather than guess. What is the radius of the Sun?'

'About 700,000 kilometres.'

'All types of radiation travel at the speed of light, right?'

'Right.'

'The speed of light is around 300,000 kilometres per second, right?'

'Right again.'

'Divide the radius by the speed and we get the time taken by the radiation to travel from the centre of the Sun to its surface. Which is – aha – a little less than two and a half seconds. Right?'

'Brilliant. But wrong!'

'Why, George, it was trivial arithmetic?'

'Mathematically correct, Alfie, but physically wrong, I am afraid,' remarked George. 'Let me explain. You can easily walk from here to your home, a couple of kilometres away in, say, fifteen minutes. Provided you are not in an inebriated state, which is normally a wrong assumption. But then, important theories are often built on wrong assumptions anyway. Well, suppose you tried to cover the same distance downtown on New Year's Eve. It may take you an hour or more. You would be colliding with every reveller and getting jostled this way and that. That is precisely what happens to each photon of radiation trying to escape from the crowded interior. It takes the poor thing thousands or even millions of years to reach the surface. Like a weary, worn-out traveller who has lost much of his energy. After that, it is a flight of a mere eight minutes in empty space from the surface of the Sun to the Earth.'

'That is most interesting, George! I never knew that.'

'Well, not many do, I must say.'

'How does this mass of hot gas in the Sun remain a spherical globe of fire instead of simply spreading out?'

'I think you know the answer, Alfie,' commented George looking at me from above his glasses. 'The answer is gravity, of course. The self-gravity of the gas pulls it towards the centre. There is a perfect balance between this inward pull of gravity and the outward pressure of the gas. And the Sun continues to exist, retaining its size and shape.'

Bruno brought the food, Zuppa Marinara and pasta. George pried open a shell, speared the mussel along with a piece of bread soaked in the Marsala sauce and placed it in his mouth. He closed his eyes in ecstasy while Bruno looked on with satisfaction.

'You know what, Bruno?' I said to Bruno as I tasted the food. 'One of your great predecessors was Brillat-Savarin. A famous French cook who lived in the seventeenth century. You know what he said? *The discovery of a new dish does more for human happiness than the discovery of a star!* Bruno, you are proving his point admirably.'

Bruno just smiled and left.

'That perceptive observation of your French cook brings us naturally to the stars,' remarked George. 'After all, the Sun is a star too. So we might as well think of the stars in general. On a clear night, you can see a couple of thousand stars with the unaided eye. A pair of binoculars would increase this number considerably. Many of the stars are in fixed patterns.'

'I know, constellations, as the ancient Greeks called them.'

'How many of them do you know?

'I can identify two or three. Like Orion the Hunter. In no way does it look like a hunter.'

'You are right, Alfie. The Greeks imagined their heroes, heroines, beasts, and demons in those stellar patterns. We have to imagine them too. Once you have done that, you will always remember the constellations and the stars that define them.'

'I suppose it works both ways.'

'How do you mean?'

'I mean the stars and the constellations could be remembered by associating them with mythological characters, right? In turn, those myths were immortalised through the stars that were considered to be eternal. So one's cultural heritage is preserved forever. That is why different cultures must have attached their legends to the stars – like the Chinese, Indians and Arabs for instance. Don't you agree?'

'You are absolutely right,' concurred George. 'But it is the Greek constellations that have remained popular. Of course, more constellations have been added to the list since the time of the Greeks. They couldn't see those that are visible only in the southern hemisphere, could they? There are eighty-eight constellations in all covering the entire dome of the sky. They come in handy for locating celestial objects. Even now, modern astronomers use them for this purpose all the time.'

'Stars belonging to the same constellation are in general at different distances from us, aren't they? Because they are all so far away, they tend to appear to be bunched together.'

'Yes, indeed! Distances of stars vary over a wide range. And so do their properties. Our Sun is an average, common-or-garden star. But there are stars that are heavier or lighter, bigger or smaller, brighter or dimmer compared to the Sun. They come in different colours too, depending on their surface temperatures. Hot stars are bluish. Cooler ones are red. Our own Sun is yellow in colour. When they stabilize after their formation, stars keep their respective colours for a long time.'

'Aha, with us humans it is different. Some yellow with age, while some mellow with age,' I observed.

'You are right. And needless to add, I belong to the second category,' said George. 'Well, all stars, including the Sun, have their own life cycles. Once again, just like humans. Birth. Existence. Death. Or BED for short. All life is a BED and we are the sleepers. It could be a BED of roses or a BED of thorns. It all depends upon how you make it.'

George was trying to strike a dramatic pose gazing at his wine glass held at arm's length. Like Hamlet holding Yorrick's skull. But it was rather comic. I could not suppress a smile.

'You are amused. Some people have no sense of the profound,' George admonished me and continued. 'Let us take a look at the birth of a star. In the vast spaces between the stars, there are huge clouds of gas and dust. You mentioned the constellation of Orion. The Great Nebula in the Orion is an example. You can see it beneath the belt of the Hunter with a pair of binoculars. Such gas clouds are the breeding grounds of stars. Here and there, the gases in the nebula clump together. As gravity pulls the gas in such a clump inwards, it starts condensing and grows increasingly dense. The temperature rises because of this compression, finally reaching millions of degrees. At such temperatures, nuclear reactions are triggered that produce immense amounts of energy. And a star is born.'

'How long does this initial process take?'

'The period of stellar pregnancy? For the gas cloud to shrink from a diameter of trillions of kilometres to the present size of the Sun, it would take, say, about ten million years. Give another twenty million years and the star will stabilise.'

'George, you guys studying stars and what not talk as though these big numbers are nothing. Do you really feel that way, or is it part of the showbiz jazz?'

'A bit of both I suppose,' George laughed. 'I guess you know your big numbers. A million is one followed by six zeroes, a billion nine zeroes, a trillion twelve zeroes and so on. Used to be called astronomical figures. Now they belong to economics as well with all the budget deficits and what not. And then there is the big measure of distance, the light-year.'

'I know that. It is the distance travelled by light in one year which amounts to about ten trillion kilometres.'

'I am impressed. How do you know these things?'

'Sometime ago, there was this patent application for a photon accelerator, which would speed up photons beyond their normal velocity. I know this is impossible. Light always travels with constant speed in a vacuum. But I learnt a lot about light waves, wave fronts, photons and all that. The estimated length of the accelerator was a few light-years. Let me describe how this accelerator is supposed to work.'

'Very interesting, Alfie, but no thank you. However, like the honest citizen that I am, let me earn my free drinks. So back to the stars,' said George. 'Birth, B, is over. Now we come to E, for existence. E also stands for equilibrium, the essence of existence. Nice alliteration, if you hadn't noticed. Anyway, you can exist only if you keep your balance among opposing forces. Stars are no exception. In the case of a star the outward pressure is created by the heat, which is in turn generated by the nuclear reactions going on at the centre. This is exactly balanced by the inward pull of gravity. We discussed this already, didn't we? So a star like our Sun remains in equilibrium, shining for about ten billion years. Our Sun is a middle-aged guy having spent almost half of his life span. No middle-age crisis though. A happy stable life for the next five billion years. Let us drink to that.'

'The pull of gravity I know. But what kind of nuclear reactions are we talking about?'

'That is exactly what I was going to tell you after toasting the sun.'

Having sipped his wine, George was about to wipe his mouth with the paper napkin on which he had been sketching.

'Hold it!' I exclaimed in alarm and stopped him.

'Why, what is the matter?' asked George a bit startled.

'You were about to wipe your mouth with the napkin on which you have been writing. Don't do that, George.'

'Why not?'

'For two reasons. Firstly, the ink may contain lead. You may get lead poisoning and your brain may become weak. Did you know that one of the causes of

the decline and fall of the Roman Empire was lead poisoning? You won't find it in your Gibbon though. But, let me tell you, the Romans started drinking their wine from lead goblets, because it tasted better that way. What happened? Their grey cells decayed and the Empire fell, goblets tumbling down like ninepins.'

'How do you know all this?'

'You see there was this patent application…' I started, but George held up his hand and stopped me.

'I am sure your patent application was absolutely fascinating, Alfie. But what was the other reason?'

'I would like to preserve your sketches and jottings as records of our discussions.'

'All right, but don't publish your notes without sharing the royalties with me,' said George, passing the napkin to me.

I must tell you something about George and me here. Both of us like to sketch and draw cartoons. So, I am going to include in my narration the drawings George made during our discussions. These technical drawings have been redrawn with the help of an artist friend to make them more presentable. I have also included some cartoons George and I have drawn for fun. I hope you will like them.

'Where were we before you rudely interrupted me?' George resumed our journey into the interior of the Sun. 'Yes, the nuclear reactions. To begin with we have these hydrogen atoms at the Sun's core stripped of their electrons. This we already discussed. At a temperature of millions of degrees in the stellar core, the hydrogen nuclei - or equivalently the protons - and the free electrons would be flying around at breakneck speeds, colliding incessantly. This enables them to interact with one another. Now the stage is set for nuclear transformations. Four hydrogen nuclei undergo a chain of reactions, combining to form the final product, namely a helium nucleus. A helium nucleus is made up of two protons and two neutrons. A neutron, as you know, is an elementary particle just like a proton. Except that it is neutral carrying no charge and it is a wee bit heavier than a proton.'

'Don't the protons carrying positive charge repel one another through electromagnetic force? How can they stick together?'

'Good question,' remarked George, and went on to give his explanation to my query. 'The answer is the nuclear forces. These forces are strongly attractive. And they overcome the electrical repulsion between protons and hold the helium nucleus together. Now here is the extraordinary fact that underlies this

nuclear fusion or the thermonuclear reaction. When you add the individual masses of the four hydrogen nuclei we started with, the sum exceeds the mass of a helium nucleus, the final product, by a minute quantity. This mass difference is converted into energy in the form of heat and radiation during nuclear fusion. The conversion is in accordance with Einstein's famous formula $E=mc^2$, which says that energy released is equal to the mass difference times the square of the speed of light.'

'A formula, which even a child knows nowadays,' I said. 'But I am a bit confused here.'

'I thought I had made myself perfectly clear. Any way, go ahead, what is your confusion?'

'Protons are indivisible elementary particles with fixed masses, aren't they?'

'Absolutely.'

'So when they form helium, chips don't fly off or anything like that thereby losing mass, do they?'

'Of course not.'

'Then how come the mass of a helium nucleus is less than the sum of the individual masses of the four protons?' I asked. 'As a matter of fact, since neutrons are a bit heavier than protons, the combined mass of two protons and two neutrons should be more than that of four protons. In other words, the helium nucleus should be heavier than the four hydrogen nuclei put together. So, why is it the other way around?'

George inclined his head and regarded me with half closed eyes. 'You do like to ask these probing questions, don't you? Quite inconvenient, I must say.'

I knew that George was inwardly quite pleased. He enjoys putting across tricky ideas in a simplified form.

'This takes some explaining. You will have to be a bit patient.'

'That is no problem. I am patience personified.'

'First of all, we can speak of mass and energy interchangeably, since they are equivalent and inter-convertible as was shown by good old Einstein. We will talk about this equivalence in a little more detail later on. So, when we talk about mass, we must include energy as well. Or, in other words, we shall be speaking of the combined mass-energy. Secondly, total mass-energy is conserved, it can neither be created nor destroyed.'

'Agreed.'

'Now let us take the helium nucleus. As you pointed out, the total mass of the two protons and the two neutrons together exceeds the mass of the helium nucleus they make up. Therefore, we come to the strange conclusion that the helium nucleus must contain an amount of negative energy exactly equivalent

to this mass difference. Equivalently, add this negative energy to the total mass of the constituents, namely two protons and two neutrons, and you get the mass of the helium nucleus. Simple arithmetic, which even you can do. This negative energy is known as the *binding energy*.'

'More and more confusion! How can energy be negative? All energy we observe and measure in nature is positive, I thought.'

'You are right. But energy too has its own credit and debit rules. Potential energy and energy in a bound system are not in a manifest form. They can be negative. You follow?'

'Not yet, but I am sure I shall, once you have completed your explanation.'

'Fair enough. Suppose you have to do work *on* a system to take it from one state to another. Then this work is stored as positive energy. For instance, take two like charges, say two protons. Far away from each other, their interaction is negligible. Now, in order to bring them near to each other, you have to do some work in overcoming their mutual repulsion. And this work becomes the positive potential energy of the two protons. They have to be held together by some other force. This can be an unstable situation. Under some external disturbance, the protons can fly apart carrying away the stored positive potential energy. This potential energy has now been converted into their kinetic energy.'

'I can think of a human analogy.'

'What is that?' George was curious to know.

'Suppose you have a couple who do not particularly like each other. And you are asked to arrange their marriage. A shotgun marriage so to speak. Then you have to put in considerable effort and do work to bring them together. The situation can be highly unstable. Some external influence, maybe a flickering flame from the past, could possibly send them flying apart.'

'Crazy analogy, but apt I must admit.'

'You have told me about positive energy. How about negative energy then?'

'All right. Now we must consider interactions that are attractive. Take, for example, the electrostatic force between two opposite charges or gravitation acting between two masses. To bring the two together you don't have to do any work at all. On the contrary, they themselves move towards each other under mutual attraction. And *they* do the work. Equivalently the work done *on* them by you is negative. Now we have a bound system with negative potential energy. Even if they are orbiting each other as in the case of an atom or planetary motion, one can show that the total energy – positive kinetic energy plus negative potential energy – is negative. Consequently, in order to take the two

particles or objects apart and break up the system, you have to do work and supply positive energy.'

'The human analogy is now in the reverse,' I commented. 'Two people in love come close to each other and bond together naturally. No external influence needed. But it takes all your effort to separate them. What a pity though! Human attraction can weaken and wane, whereas physical forces in nature are permanent.'

'True enough. Now, when we deal with elementary particles and their interactions, we are in the realm of quantum theory, which is radically different from classical physics. Nevertheless, the underlying principle is the same. In the case of nuclear fusion, four protons are brought together through collisions at high temperature overcoming their mutual repulsion. Because of the ensuing nuclear reactions, we are left with two protons and two neutrons forming a helium nucleus. The nuclear interaction among them is extremely strong and moreover attractive. This leads to the negative binding energy of the nucleus, which is responsible for the lower mass of the helium nucleus as compared to its constituents, namely two protons and two neutrons. Furthermore, the mass of the helium nucleus turns out to be less than that of the four protons we started with as well. And, as we saw, this mass difference is released during nuclear fusion. Got it?'

'Ah, I think I understand the energetics of nuclear fusion now,' I said. 'How about nuclear fission?'

'Well, the energy principle works in the case of nuclear fission also. You initially have a heavy nucleus with some binding energy. By fission, you can split the nucleus into fragments – elements lighter than the original one – whose internal binding is stronger. This makes for a more stable configuration.'

'Like having a large commune to begin with, but finding that it would be a happier and healthier situation to break it up into smaller families.'

'Alfie, your analogies are getting crazier and crazier!' exclaimed George.

'That is because the physics is becoming stranger and stranger,' I countered.

'I think you are right,' admitted George and continued. 'Coming back to nuclear fission, a slow neutron can break up a uranium nucleus into barium and krypton – almost equal fragments – releasing nuclear energy. Three more neutrons are ejected in this process leading to a chain reaction splitting more and more nuclei. This process is used in nuclear reactors for energy production.'

'Or in making a nuclear bomb.'

'That is right, unfortunately. Whew, that was quite a bit of explanation, don't you agree? I must wet my whistle.'

After a pause George continued. 'Let us get back to the interior of the Sun. The energy generated in a single thermonuclear reaction, when four hydrogen atoms combine to form a helium atom, is minute. But the Sun is huge, containing an enormous amount of hydrogen. Each second at the Sun's core 564 million tons of hydrogen are converted into 560 million tons of helium.'

'Which means every second 4 million tons of mass are transformed into energy. And you have to multiply this by the square of the speed of light to get the actual amount of energy released. How much would that be, George?'

George took out a small piece of paper from one of his pockets. Scrawled on them were some numbers. 'I have jotted down some figures that should interest you. You will probably file them away somewhere in your head. You know what a watt is?'

'Come on, George, every one who pays electricity bills knows that. It is the unit of power, the energy generated or consumed per second, named after James Watt, the inventor of the steam engine. Maybe a tautology, but a hundred-watt light bulb obviously uses up a power of hundred watts.'

'Good. Each second, the Sun generates some 400 trillion-trillion watts of power. Remember a trillion is one followed by 12 zeroes, so the energy released within the solar core measured in watts is 4 followed by 26 zeroes. Now the total amount of electrical power being used in the whole world is about 10 trillion watts. In other words, the energy the sun produces in one second is equivalent to what mankind would use in 40 trillion seconds or in a million years!'

'What a monstrous irony!'

'How do you mean?'

'The same thermonuclear energy, that keeps the sun shining, causes the explosion of a hydrogen bomb, doesn't it?'

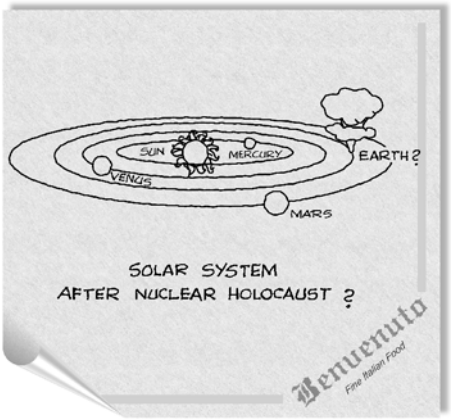
'Again, unfortunately, yes,' answered George.

'I remember that if one ton of TNT explodes in a second, it yields a power of 4 billion watts.'

'That means that in one second the sun produces an energy equivalent of 100 billion megatons of TNT.'

'Those numbers make your head swim, don't they? All that energy in terms of tons of TNT is confined to the sun. But look at what is happening right here on the earth. The most powerful hydrogen bomb is equivalent to about 60 megatons of TNT. And the stockpiled nuclear arsenal amounts to some ten thousand megatons of TNT. For every human being there is more than a ton of TNT in store. Enough to wipe out the entire human race many times over!'

George had been sketching while we were having this conversation. He showed me what he had drawn. It was a schematic diagram of the Solar System. 'This is how the Solar System would look like if there were ever to be a nuclear holocaust, Alfie,' sighed George. The drawing showed an enormous mushroom cloud orbiting the sun where the earth should have been. It gave me a sick feeling.



'Sorry, Alfie. Let us get back to the Sun, which is a more cheerful subject,' George said and continued. 'So in the Sun's core the hydrogen keeps burning. This is not really ordinary burning, as we know. But that is the way the heat production through nuclear reactions is colloquially described. The nuclear furnace at the heart of the Sun keeps going for ten billion years. Of which five billion years are already gone. Sun shines on. But then the situation takes a dramatic turn. It is a somewhat complex story from now on. Let me give you a brief, simplified account of the events that follow. I shall concentrate more on the Sun.'

'Ah, our own nearest and dearest star!'

'Let me warn you. I am leaving out many details and may not follow the exact order of changes that occur within the Sun.'

'Whatever you say, boss,' I agreed.

Bruno served us dessert, Biscuit Tortoni with a creamy hazelnut sauce, and withdrew. George took a bite and continued.

'Now, in ten billion years most of the hydrogen at the Sun's core would be converted into helium. There is no longer enough heat production to balance the gravity of the core's mass. So what happens? The core shrinks under its own weight and gets heated up. And this heat is conveyed to the shell surrounding the core. The shell is of course made up of hydrogen, which starts burning. The outer part of the Sun in turn gets heated and bloats up. And as you know, an expanding gas cools down. So, the surface temperature drops because of this expansion. The Sun, grown gigantic by now, glows red. The Sun has turned into a red giant.'

'How big is gigantic?' I wanted to know.