# Selected Physical and Astronomical Constants

[Inside front cover, left]

| | |
|---|---|
| Gravitational constant | $G = 6.67 \times 10^{-11}$ meter$^3$/(kilogram-second$^2$) |

### EARTH

| | |
|---|---|
| Mass of Earth | $M_{\mathrm{E}} = 5.97 \times 10^{24}$ kilogram<br>$= 4.44 \times 10^{-3}$ meter |
| Equatorial radius of Earth | $r_{\mathrm{E}} = 6.38 \times 10^{6}$ meter |
| Gravitational acceleration on Earth | $g_{\mathrm{E}} = 9.81$ meter/second$^2$<br>$= 1.09 \times 10^{-16}$ meter$^{-1}$ |
| Mean distance of Earth from Sun $\equiv$ 1 astronomical unit (AU) | $1\,\mathrm{AU} = 1.50 \times 10^{11}$ meter |
| Mean speed of Earth in its orbit around Sun | $v_{\mathrm{E}} = 2.98 \times 10^{4}$ meter/second |

### OUR SUN

| | |
|---|---|
| Mass of the Sun | $M_{\mathrm{Sun}} = 1.99 \times 10^{30}$ kilogram<br>$= 1.48 \times 10^{3}$ meter |
| Radius of the Sun | $r_{\mathrm{Sun}} = 6.96 \times 10^{8}$ meter |

### OUR UNIVERSE

| | |
|---|---|
| Age of the Universe | $= (13.7 \pm 0.1) \times 10^{9}$ year<br>$= 1.30 \times 10^{26}$ meter |
| Hubble constant now | $H_0 = 72 \pm 2$ (kilometer/second)/Megaparsec<br>$= 7.37 \times 10^{-11}$ (light year) $^{-1}$<br>$= 7.78 \times 10^{-27}$ meter$^{-1}$ |

# Conversion Factors

Speed of light in a vacuum (by definition): $c \equiv 2.997\,924\,58 \times 10^{8}$ meter/second

1 second $\approx 3.00 \times 10^{8}$ meter of light-travel time

1 meter of light-travel time $= 3.34 \times 10^{-9}$ second

1 year $= 3.16 \times 10^{7}$ second $= 9.46 \times 10^{15}$ meter of light-travel time

1 light-year$= 3.16 \times 10^{7}$ second $\times\, c$ $= 9.46 \times 10^{15}$ meters

1 kilometer $= 0.621$ mile

1 kilogram $= 7.42 \times 10^{-28}$ meter of mass $= 5.61 \times 10^{32}$ electron-volt

1 parsec $= 3.26$ light year

## Approximation

$(1+\epsilon)^n \approx 1 + n\epsilon + O\left(\epsilon^2\right)$ $\qquad$ $(|\epsilon| \ll 1$ and $|n\epsilon| \ll 1)$

**For time in unit of meter, see Chapter 1, Speeding**
**For mass in unit of meter, see Chapter 3, Curving**

Can I see a black hole at all? If I can see it, what does a black hole look like? Does it *look* black? Where do black holes exist in the Universe? Does the black hole look different when I fall toward it? What does it *feel* like to fall into a black hole? Am I comfortable? Do I see the stars overhead as I fall into a black hole? If so, do these stars change position or color as I fall? How fast do I fall? Does my speed reach or exceed the speed of light? Once inside, can I receive messages and packages from my friends on the outside? Is it true that, once inside, I cannot send anything to my friends on the outside, not even a light signal? *Why* can't I send them messages? How long do I live once I fall into a black hole? Will I reach the center alive? Can I see the crunch-point ahead of me? What is the last thing I see? Is my death quick and painless? What happens to the mass of a black hole when it swallows me or swallows a stone? How does the orbit of a stone around a black hole differ from the orbit of a planet around our Sun? Newton says a planet stays in orbit because the Sun exerts a gravitational force on it. How does Einstein explain this orbit? If Newton and Einstein disagree, how do we decide between them? How close to a black hole can I move in a circular orbit? Can I use a black hole to travel rapidly forward in time? backward in time? What are the upper and lower limits on the mass of a star, a white dwarf, a neutron star, a black hole? Which of these bodies require general relativity for its correct description? In what sense are space and time unified? Why do things fall in my everyday life on Earth? Does the term *relativity* mean that everything is relative? What does *curvature* mean? How can I observe curvature? How many different observed effects does curvature account for? How does the Global Positioning System fail if we ignore general relativity? How much does light change direction as it passes the Sun or a black hole? Does the amount of change in direction depend on the color of the light? How does an astronomical object focus light from a distant galaxy and what does the image of that distant galaxy look like? Can light go into a permanent orbit around a black hole? How fast can a black hole spin? Does a spinning black hole drag space around with it? What does "drag space" *mean*; how can I observe it? Can I extract energy from a spinning black hole? What is a quasar? Do spinning black holes power quasars; if so, how? What are gravitational waves? What can gravitational waves tell us about the Universe that light cannot? How far away is the most distant galaxy that we see? Is the Universe just a big black hole? How did the Universe begin? What is the Universe made of? What does the *Big Bang* mean and how do we know it happened? Did time and space exist before the Big Bang? Why does the Universe expand with time? What is the Universe expanding into? Why is the expansion of the Universe speeding up? Where is the center of the Universe, anyway? How will the Universe end—or will it go on forever? Will the Earth exist twenty billion years from now? Whether or not the Earth exists then, what will the heavens look like from the position of our solar system?

*Curiosity, like coffee, is an acquired need. Just a titillation*
*at the beginning, it becomes with training a raging passion.*
—Nicholas S. Thompson

*I have no special talents. I am only passionately curious.*
—Albert Einstein

[Title page, right-hand side]

# EXPLORING BLACK HOLES

## INTRODUCTION TO GENERAL RELATIVITY

**Second Edition**

**Edwin F. Taylor**

**John Archibald Wheeler**

**Edmund Bertschinger**

[Right-hand page]

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*It is not my purpose in this discussion to represent the general theory of relativity as a system that is as simple and as logical as possible, and with the minimum number of axioms; but my main object here is to develop this theory in such a way that the reader will feel that the path we have entered upon is psychologically the natural one, and that the underlying assumptions will seem to have the highest possible degree of security.*

—Albert Einstein

*Everything important is, at bottom, utterly simple.*

—John Archibald Wheeler

[REFERENCES:

First quote: Albert Einstein, "The Foundation of the General Theory of Relativity" in *The Principle of Relativity*, translated by W. Perrett and G. B. Jeffery, 1952 Dover Publications, ISBN 0486600815, page 118.

Second quote in Robert Oerter in *The Theory of Almost Everything: The Standard Model, The Unsung Triumph of Modern Physics*, 2006.]

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