INKPHYSICS FLASHCARDS

Turning points

Year 13 · 17 cards · fronts and backs

Print double-sided, flipping on the long edge, and each answer lands behind its question. Cut along the card borders.

Definitions in mark-scheme wording, the equations that are not on the data sheet, each lesson's check question, and the misconceptions that lose marks. The same cards run on the website with spaced-repetition scheduling, at inkphysics.co.uk/flashcards.

DEFINITION

Define: Specific charge of the electron.

CATHODE RAYS AND THE ELECTRON

CHECK YOURSELF

Show that the classical formula $eV = \frac{1}{2}mv^2$ predicts electrons reaching the speed of light at an accelerating pd of about 260 kV, and comment on what this suggests.

Hint: Set $v = c$ and solve for V using $e/m = 1.76 \times 10^{11}$ C kg^{-1}.

CATHODE RAYS AND THE ELECTRON

SPOT THE ERROR

Say what is wrong with this claim:

The atom is the smallest unit of matter; nothing can be pulled out of one.

CATHODE RAYS AND THE ELECTRON

EQUATION — NOT ON THE DATA SHEET

The balanced oil drop:

$(QV)/(d) = ?$

MILLIKAN'S OIL DROP EXPERIMENT

CHECK YOURSELF

A droplet weighing 3.84×10^{-14} N hangs stationary between plates 6.0 mm apart with 480 V across them. Find the droplet's charge, and state how many electrons' worth it carries.

Hint: Rearrange $QV/d = mg$ for Q; the weight mg is given whole.

MILLIKAN'S OIL DROP EXPERIMENT

SPOT THE ERROR

Say what is wrong with this claim:

Electric charge comes in any amount you like, like water from a tap.

MILLIKAN'S OIL DROP EXPERIMENT

CHECK YOURSELF

Explain why Young's 1801 experiment did not immediately overturn the corpuscular theory, and name the two later results that settled the wave theory's victory.

Hint: One reason is about people; the two results are a speed comparison and a prediction confirmed.

THE NATURE OF LIGHT

SPOT THE ERROR

Say what is wrong with this claim:

A theory backed by a great enough scientist counts as proved.

THE NATURE OF LIGHT

CHECK YOURSELF

$V = v^2/(2e/m) = (3.0 \times 10^8)^2 / (2 \times 1.76 \times 10^{11}) = 2.6 \times 10^5$ V: about 260 kV.

Laboratory supplies exceed this easily, yet no electron has ever been observed at or beyond the speed of light.

So the classical formula must fail at high speeds. What actually happens near 260 kV, and why, is the business of this unit's relativity lessons.

CATHODE RAYS AND THE ELECTRON

DEFINITION

The electron's charge divided by its mass, e/m: Thomson measured it at about 1800 times hydrogen's, the first evidence for a particle smaller than an atom.

CATHODE RAYS AND THE ELECTRON

EQUATION — NOT ON THE DATA SHEET

$(QV)/(d) = mg$

MILLIKAN'S OIL DROP EXPERIMENT

SPOT THE ERROR

Thomson's cathode rays ended the indivisible atom: their charge-to-mass ratio came out about 1800 times hydrogen's, the same whatever the cathode metal. Something far lighter than any atom — the electron — had been pulled out of every one.

CATHODE RAYS AND THE ELECTRON

SPOT THE ERROR

Charge is quantised: Millikan's droplets never carried arbitrary charge, only whole multiples of 1.6×10^{-19} C. Charge comes in electron-sized instalments, never a smooth flow like water.

MILLIKAN'S OIL DROP EXPERIMENT

CHECK YOURSELF

$Q = (\text{weight} \times d)/V = (3.84 \times 10^{-14} \times 6.0 \times 10^{-3}) / 480 = 4.8 \times 10^{-19}$ C.

$4.8 \times 10^{-19} / 1.6 \times 10^{-19} = 3$: the droplet carries three electrons' worth of charge.

A non-integer answer here means an arithmetic slip, and that check, whole numbers or nothing, is Millikan's discovery in miniature.

MILLIKAN'S OIL DROP EXPERIMENT

SPOT THE ERROR

Reputation is not evidence: Newton's corpuscles predicted light travels FASTER in glass, waves predicted slower. When Foucault measured it, the wave side won — and a century of deference to Newton went with it.

THE NATURE OF LIGHT

CHECK YOURSELF

Newton's authority kept the corpuscular theory respectable, and one experiment, however clean, was not enough to displace a century of consensus: acceptance of the wave picture was delayed for decades.

Measurements descended from Fizeau's method showed light travelling slower in water than in air, as the wave theory required and the corpuscular theory contradicted.

Maxwell's $c = 1/\sqrt{(\mu_0 \varepsilon_0)}$ matched the measured speed of light, and Hertz then produced electromagnetic waves directly, at that same speed: light was a wave, and an electromagnetic one.

THE NATURE OF LIGHT

CHECK YOURSELF

In a low-energy electron diffraction experiment the accelerating pd is doubled. Explain what happens to the ring pattern, and why an electron microscope can resolve detail no light microscope can reach.

Hint: Follow the chain pd, momentum, wavelength, and remember resolution follows wavelength.

QUANTA AND WAVE-PARTICLE DUALITY

SPOT THE ERROR

Say what is wrong with this claim:

Waves are waves and particles are particles, and nothing is ever both.

QUANTA AND WAVE-PARTICLE DUALITY

DEFINITION

Define: Inertial frame of reference.

THE MICHELSON-MORLEY EXPERIMENT

CHECK YOURSELF

State the two postulates of special relativity, and explain which one the Michelson-Morley result supports and how.

Hint: The fringes that refused to move are a statement about one particular speed.

THE MICHELSON-MORLEY EXPERIMENT

SPOT THE ERROR

Say what is wrong with this claim:

Light must travel through something; empty space cannot carry a wave.

THE MICHELSON-MORLEY EXPERIMENT

DEFINITION

Define: Proper time.

THE CONSEQUENCES OF SPECIAL RELATIVITY

DEFINITION

Define: Rest mass.

THE CONSEQUENCES OF SPECIAL RELATIVITY

CHECK YOURSELF

A spacecraft passes Earth at 0.60c. Its on-board clock records 100 s between two ticks, and its proper length is 50 m. Find the time between those ticks and the craft's length as measured from Earth, and state which measurement each observer would call "correct".

Hint: The root is $\sqrt{(1 - 0.36)} = 0.80$; decide which quantity dilates and which contracts.

THE CONSEQUENCES OF SPECIAL RELATIVITY

SPOT THE ERROR

The photoelectric effect forces particle behaviour on light, and electron diffraction forces wave behaviour on matter. Nature refuses the clean division: everything propagates like a wave and exchanges energy like a particle.

QUANTA AND WAVE-PARTICLE DUALITY

CHECK YOURSELF

Doubling V multiplies the momentum by $\sqrt{2}$, so $\lambda = h/p$ falls by a factor of $\sqrt{2}$, and the rings shrink by that factor: faster electrons, shorter waves, tighter pattern.

Resolution is limited to roughly the wavelength used. Electrons at even 150 V carry $\lambda \approx 10^{-10}$ m, thousands of times shorter than visible light's 5×10^{-7} m.

So an electron microscope resolves atomic-scale structure that no arrangement of glass lenses ever could: wave-particle duality, turned into an instrument.

QUANTA AND WAVE-PARTICLE DUALITY

CHECK YOURSELF

One: physical laws have the same form in all inertial frames. Two: the speed of light in free space is invariant, the same for every inertial observer.

The null result supports the second. The two beams' round trips tied exactly, whatever the Earth's motion through space and however the arms were oriented.

So the measured speed of light does not depend on the motion of the apparatus carrying the source and detector, which is precisely the invariance the second postulate asserts.

THE MICHELSON-MORLEY EXPERIMENT

DEFINITION

A frame moving at constant velocity, in which Newton's first law holds.

THE MICHELSON-MORLEY EXPERIMENT

DEFINITION

The time between two events measured in the frame where they happen at the same place: the shortest time any observer records, t_0.

THE CONSEQUENCES OF SPECIAL RELATIVITY

SPOT THE ERROR

The interferometer was sensitive enough to catch the supposed aether wind, and found nothing — in any season, any orientation. Light needs no medium: its speed is the same in every inertial frame, the invariance relativity is built on.

THE MICHELSON-MORLEY EXPERIMENT

CHECK YOURSELF

Time: the ticks happen at the ship, so 100 s is proper time, and Earth measures $t = 100/0.80 = 125$ s: the moving clock runs slow.

Length: 50 m is proper length, and Earth measures $l = 50 \times 0.80 = 40$ m, contracted along the motion.

Both are correct. Each observer's measurements are right in their own inertial frame; relativity's content is precisely that these quantities are frame-dependent, with the proper values belonging to the frame riding with the clock and the rule.

THE CONSEQUENCES OF SPECIAL RELATIVITY

DEFINITION

The mass of an object measured in the frame where it is at rest: m_0.

THE CONSEQUENCES OF SPECIAL RELATIVITY

SPOT THE ERROR

Say what is wrong with this claim:

With a strong enough accelerator you could push an electron past the speed of light.

THE CONSEQUENCES OF SPECIAL RELATIVITY

SPOT THE ERROR

As speed approaches c, the energy needed grows without limit — the effective mass rises as $m_0/\sqrt{(1 - v^2/c^2)}$, which blows up at v = c. Accelerators push electrons to 0.9999c and beyond, but each extra decimal place costs vastly more energy, and c itself is never reached.