PHAS 1202 ASU

WAVES AS PARTICLES UNTIL 19th CENT → light had been established as a particle (Newtonian theory).

Interference effects could not be explained by particle theory.

YOUNG'S DOUBLE SLIT EXPERIMENT 1803 : shine monochromatic light through two equally spaced, small slits.

* bright fringes, integer > path difference CONSTR. INT.
* dark fringes, ANTIPHASE DESTR. INT.

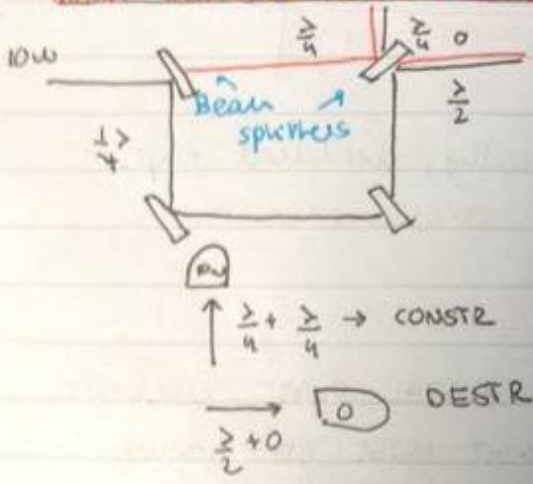
PHASE SHIFT BY PATH DIFFERENCE.

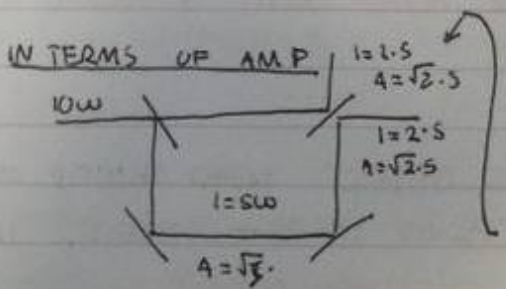
→ STRONG EVIDENCE VS PARTICLE THEORY (particle can't know if both slits open + choose fringe to land on.

- Amplitude : max displ. from rest point
- Intensity : (amplitude)^2

INTERFERENCE OCCURS ON LEVEL OF AMPLITUDE.

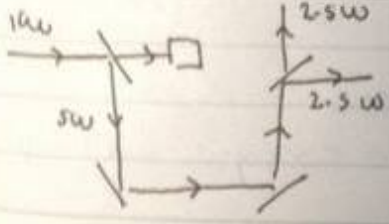
MACH-ZEHNDER INTERFEROMETER Beam-splitters → used detector mirrors transmit 50%, reflect 50%. REFL cause phase shift $\frac{\lambda}{4}$. Path difference constructed so as = same





$A_{total} = 2\sqrt{2}\cdot 5$
$= \sqrt{4}\sqrt{2}\cdot 5$
$= \sqrt{10}$
$I = \sqrt{10}^2 = 10\,W$

BLOCK ONE OF CHANNELS : CLASSICAL PARTICLE CAN'T TRAVEL BOTH PATHS



→ CLASSICAL PARTICLE CANNOT BE SPLIT

LIGHT = WAVE

☆ LIGHT AS PARTICLE

① **BLACK BODY RADIATION** BLACK BODY : idealised object which absorbs all light incident on it. in thermal eq. emits radiation if light is incident upon it.

STEFAN'S LAW $\left[P = \sigma A T^4 \right]$ $\sigma = 5.7 \times 10^{-8}\ W/m^2$

P: POWER, A: AREA

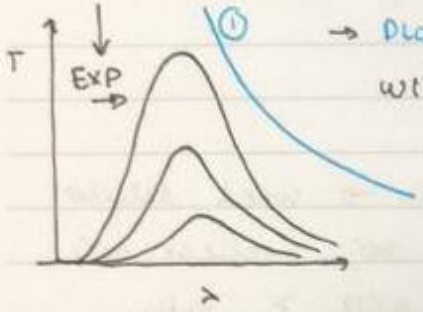
WIEN'S LAW $\left[\lambda_{max} T = 2.9 \times 10^{-3}\ m.K \right]$

λ_{max}: PEAK WAVELENGTH

UV CATASTROPHE

Rayleigh-Jeans tried to theoretically derive black-body emission spectra : ① $I(\lambda, T) = \frac{2\pi c k T}{\lambda^4}$

Exp → $\lambda \to 0$ $I \to 0$ but in formula $I \to \infty$



→ Planck proposed quantizing light energy with $\left[E = hf \right]$

PLANCK'S LAW

$$\left[I(\lambda, T) = \frac{2\pi h c^2}{\lambda^5 (e^{hc/\lambda k T} - 1)} \right]$$

$h = 6.626 \times 10^{-34}$ Js → found theoretically, matched exp.

∴ PLANCK FOUND LIGHT BEHAVED IN SMALL PACKETS.

② **PHOTOELECTRIC EFFECT** LIGHT SHINED ON METAL PLATE, CURRENT FLOWS THROUGH CIRCUIT. LIGHT MUST BE ABOVE THRESHOLD FREQUENCY.

EINSTEIN PROPOSED:

① QUANTISED LIGHT

② e^- can absorb photons 1 by one

③ each e^- → binding energy to escape metal

$E = hf > \phi$ (work fnction) $\rightarrow e^-$ escape.

③ PHOTON MOMENTUM EM PREDICTS LIGHT HAS MOMENTUM

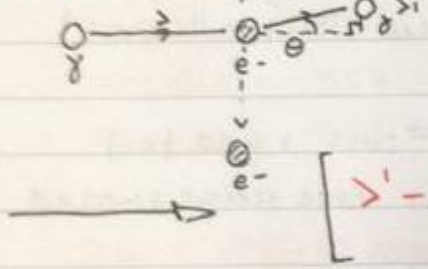
$E = mc^2$ $p = \frac{E}{c}$, $E = hf$ $p = \frac{hf}{c}$ $\left[p = \frac{h}{\lambda}\right]$

RADIATION PRESSURE CAN BE PREDICTED W CLASSICAL EM for macro. objects.

④ COMPTON EFFECT

1922 → THOMSON EFFECT : incident X-rays cause e^- oscillate and emit X-RAYS at same freq.

COMPTON OBSERVED SCATTERED X RAYS HAD ANGLE DEPENDENT SHIFT. proposed scalling as particles.



MOM CONS : e^- recoil

EN. CONS : loss of energy, longer λ.

$\left[\lambda' - \lambda = \frac{h}{mec}(1 - \cos\theta)\right]$ WAV SHIFT IS SOLELY ANGLE DEPENDENT.

WAVE EVIDENCE	PARTICLE EVIDENCE
- YOUNG'S DOUBLE SLIT	- BLACK BODY RAD
- MACH-ZEHNDER	- PHOTOELECTRIC EFFECT
	- PHOTON MOM.
	- COMPTON SCATTERING

PHOTONS + M-Z EXP

→ INTENSITY TO 1 γ/s ; Double slit w individual particles builds up interference pattern. Intensity

$$\left[P(a \le x \le b) = \int_a^b \underset{\text{prob density}}{\rho(x)}\, dx \right]$$

$$\left[\int_{-\infty}^{\infty} \rho(x)\, dx = 1 \right] \text{ NORMALISATION CONDITION}$$

$$\left[\int_{-\infty}^{\infty} |\psi(x)|^2\, dx = 1 \right] \quad \psi(x)^2 \to \text{+ve}, \ \text{MOD} \to \text{complex nos}$$

NORMALISING ψ:

- when $\int_{-\infty}^{\infty} |\psi(x)|^2\, dx = N \neq 1$
- $\psi_2(x) = \dfrac{\psi_1(x)}{\sqrt{N}}$

→ $\psi(x)$ must be continuous

- $\dfrac{d\psi(x)}{dx}$ → finite : must also be continuous
  - → $\dfrac{d^2\psi(x)}{dx^2}$ → finite.

$\psi(x)$:
- F(x) position of particle
- +ve / -ve , complex ... all value x.
- normalised
- continuous (in 1st derivative also)
- Born's rule $P(a \le x \le b) = \int_a^b |\psi(x)|^2\, dx$

EXPECTATION VALUE : mean value of value obtained in exp.

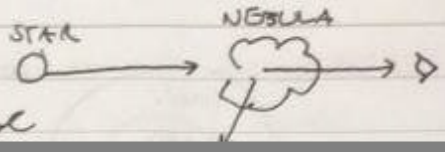
$$\left[\langle x \rangle = \int_{-\infty}^{\infty} \rho(x)\, x\, dx \right]$$

→ $$\langle x \rangle = \int_{-\infty}^{\infty} |\psi(x)|^2\, x\, dx$$

Eg. De Broglie wave $\psi(x) = \sin\left(\frac{px}{\hbar}\right)$

NORMALISED? $\int^{\infty} \sin^2 px\, dx$

• ABSORPTION FEATURE



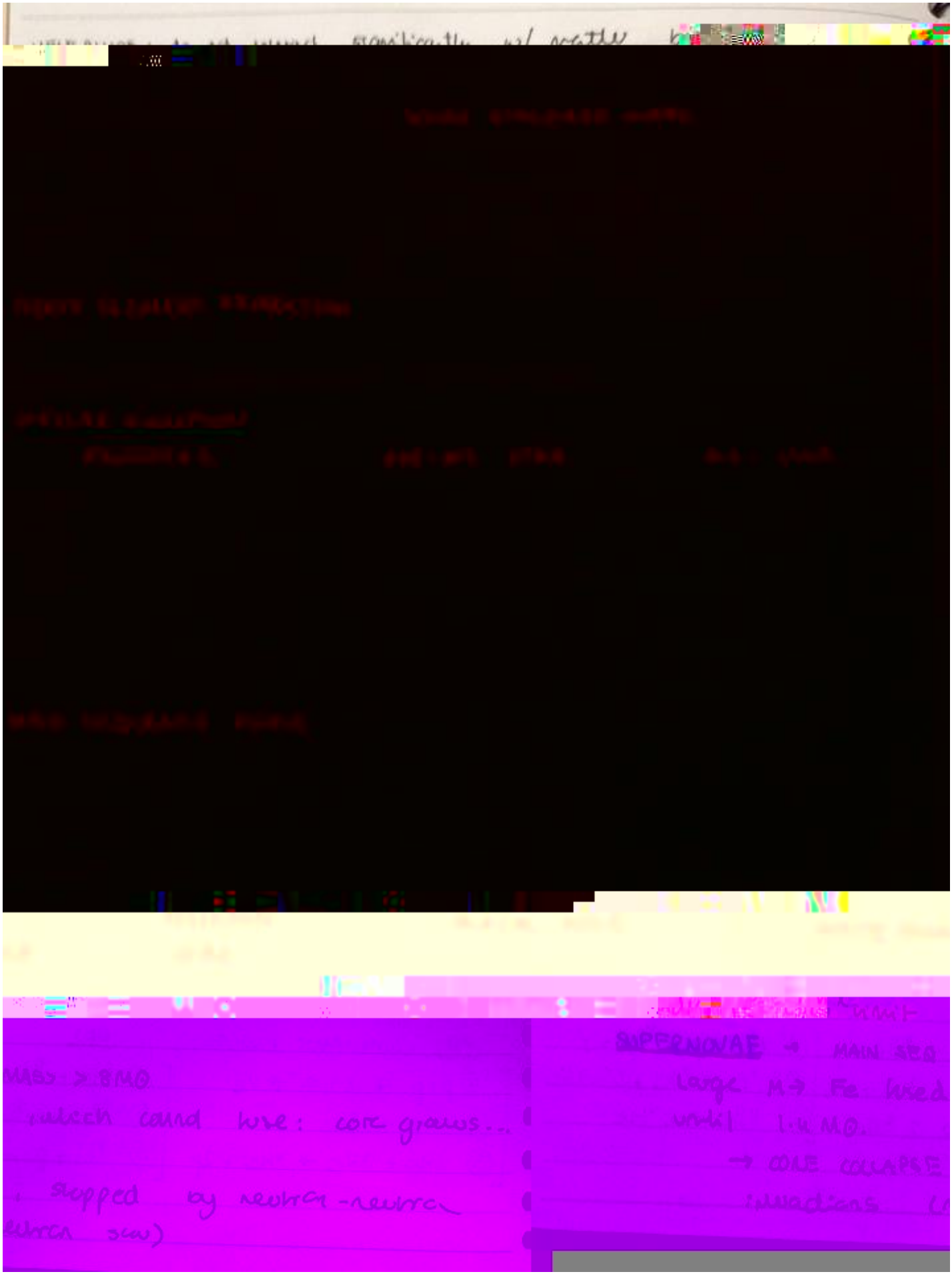
observed seen all but those

③ STELLAR EVOLUTION

Stars = stable : assume thermal pressure + grav. force acting upon them:

$$\frac{dP}{dr} = -\frac{GM(r)}{r} \cdot \rho(r)$$

For [illegible] occur, certain conditions



→ CORE BOUNCES BACK → infalling layers rebound
shock wave material. Total E released ~10^{46} J Nebula
supernova remnant ~ 10^{44} J KE.

IF CORE > 3M⊙ (MS mass > 20M⊙)
↳ BLACK HOLE Vol = 0 ρ = ∞ (singularity)
so dense, grav field = so strong → light cannot escape
Escape limit = event horizon
Schwarzschild radius $R_{Sch} = \frac{2GM}{c^2}$ ← M BH

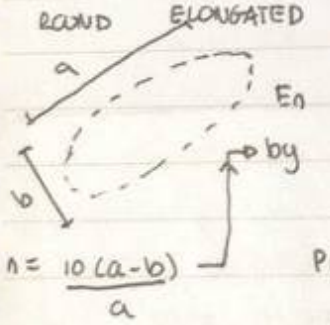
Black hole = body contained within ↑
observed by influence on material around it.
→ Gains KE → ionised → radiate (x rays)
→ Roche lobe (volume controlled by G of BH) = large
→ most efficient
→ drawing gas from lobe = accretion

⑪ GALAXIES classified by morphology.

★ ELLIPTICAL

- spheroidal w little/no texture
- orbits of stars are randomly oriented
- star formation complete, gas consumed
- old stars (old as galaxy)
- little/no gas
- "smooth" structure

EO → E6
ROUND ELONGATED



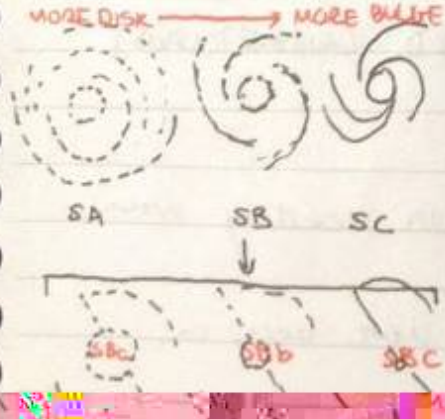
$n = \frac{10(a-b)}{a}$

PROJECTION EFFECT → observed shape vs real shape

★ SPIRAL GALAXIES

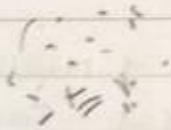
MORE DISK → MORE BULGE

- flattened systems that rotate
- orbits of stars = circular about disc axis
- star formation ongoing
- gas/dust = 10-50% of disk mass
- age of stars/galaxy → new
- star formation in spiral arms



→ MORE BAR

★ IRREGULAR : no structure



SPIRAL GALAXIES caused by compression of gas, which means star formation.

EVIDENCE : [• Abundance lightest elements • Evolution of universe
• CMBR • expansion of universe]

CMBR : Radiation from early universe was detected in 1960s.
→ Initially, universe was fully ionized : opaque to e^-

[redacted]

Expansion measured using type Ia supernovae

→ EXPANSION FOUND ACC. (expected decc.)

↳ explained by Λ, accounts for missing mass/energy