

LAST (Family) NAME: _____

FIRST (Given) NAME: _____

STUDENT NUMBER: _____

UNIVERSITY OF TORONTO
Faculty of Arts and Science
APRIL 2023 EXAMINATIONS
PHY 357 H1S
Particle and Nuclear Physics
Duration: 3 hours

**Aids allowed: Non-Programmable scientific calculator, without text storage
One, personally prepared (not mechanically photo-copied/photo-reduced), aid-sheet
(materials can appear on both sides of a single 8.5" x 11" sheet).**

Exam Reminders:

- Fill out your name and student number at the top of this page.
- Do not begin writing the actual exam until the announcements have ended and the Exam Facilitator has started the exam.
- As a student, you help create a fair and inclusive writing environment. If you possess an unauthorized aid during an exam, you may be charged with an academic offence.
- Turn off and place all cell phones, smart watches, electronic devices, and unauthorized study materials in your bag under your desk. If it is left in your pocket, it may be an academic offence.
- When you are done your exam, raise your hand for someone to come and collect your exam. Do not collect your bag and jacket before your exam is handed in.
- If you are feeling ill and unable to finish your exam, please bring it to the attention of an Exam Facilitator so it can be recorded before leaving the exam hall.
- In the event of a fire alarm, do not check your cell phone when escorted outside.

Special Instructions:

There are **six** questions on this exam. You must answer **five** of them. Each answer is worth **20 %** of the full examination grade. If you answer more than five please indicate which five you want to count, otherwise only the first five attempted will be graded and included in your final score.

Partial credit will be given for partially correct answers, so show any intermediate calculations that you do and write down, **in a clear fashion**, any relevant assumptions you are making along the way.

There are two pages of background material, not all of which you'll need to answer the questions, that are found on pages two and three of this paper. The questions start on page **four** and continue to page **six**.

Students must hand in all examination materials at the end.

PHYSICS 357S – Constants and Particle Properties

Possibly Useful Physical Constants:

Avogadro No:	$6 \times 10^{23} \text{ mole}^{-1}$
pi	$\pi = 3.1416$
speed of light:	$c = 3.0 \times 10^8 \text{ m/s}$
Plank's constant:	$\hbar = 6.6 \times 10^{-22} \text{ MeV} \cdot \text{s}$ $\hbar c = 197 \text{ MeV} \cdot \text{fm}$ $(\hbar c)^2 = 0.4 \text{ GeV}^2 \cdot \text{mb}$
	$1 \text{ eV} = 1.6 \times 10^{-19} \text{ Joules}$
	$1 \text{ eV}/c^2 = 1.8 \times 10^{-36} \text{ kg}$
	$1 \text{ fm} = 10^{-15} \text{ m}$
	$1 \text{ mb} = 10^{-27} \text{ cm}^2$
1 year	$1 \text{ year} \approx \pi \times 10^7 \text{ s}$
electron charge:	$e = 1.602 \times 10^{-19} \text{ C}$
electron magnetic moment:	$\mu_e = 9.3 \times 10^{-24} \text{ Joules} \cdot \text{Tesla}^{-1}$
fine structure constant:	$\alpha = e^2/(\hbar c) = 1/137.0360$
strong coupling constant:	$\alpha_s(M_Z) = 0.116 \pm 0.005$
Fermi coupling constant:	$G_F = 1.166 \times 10^{-5} \text{ GeV}^{-2}$
Cabibbo angle:	$\sin \theta_C = 0.22$
Weak mixing angle:	$\sin^2 \theta_W(M_Z) = 0.2319 \pm 0.0005$
Branching Ratios	$BR(Z \rightarrow e^+ e^-) = 3.21 \pm 0.07\%$ $BR(Z \rightarrow \text{hadrons}) = 71 \pm 1\%$
Electromagnetic constant	$1/(4\pi\epsilon_0) = 8.99 \times 10^9 \text{ Nm}^2 / \text{C}^2$

Particle Properties

Boson	Mass (GeV/c^2)
γ	$< 3 \times 10^{-36}$
gluon	~ 0
W^\pm	80.22
Z^0	91.187
H^0	125

Lepton	Mass (MeV/c^2)	Lifetime (s)
ν_e	$< 10^{-5}$	-
e	0.510999	$> 10^{33}$
ν_μ	< 0.27	-
μ	105.658	2.197×10^{-6}
ν_τ	< 10	-
τ	1777	2.906×10^{-13}

Hadron	Quark Content	Mass (MeV/c^2)	$I(J^{PC})$
π^+, π^0, π^-	$u\bar{d}, (u\bar{u} - d\bar{d})/\sqrt{2}, d\bar{u}$	139.57, 134.97, 139.57	$1(0^{+-})$
K^+, K^-	$u\bar{s}, s\bar{u}$	493.65	$\frac{1}{2}(0^-)$
K^0, \bar{K}^0	$d\bar{s}, s\bar{d}$	497.67	$\frac{1}{2}(0^-)$
ρ^+, ρ^0, ρ^-	$u\bar{d}, (u\bar{u} + d\bar{d})/\sqrt{2}, \bar{u}d$	775.7	$1(1^{--})$
p, n	uud, udd	938.27, 939.57	$\frac{1}{2}\left(\frac{1}{2}^+\right)$
$\Delta^-, \Delta^0, \Delta^+, \Delta^{++}$	ddd, udd, uud, uuu	1232	$\frac{3}{2}\left(\frac{3}{2}^+\right)$
Λ^0	uds	1115.6	$0\left(\frac{1}{2}^+\right)$
\bar{D}^0, D^0	$u\bar{c}, c\bar{u}$	1863	$\frac{1}{2}(0^-)$
D^-, D^+	$d\bar{c}, c\bar{d}$	1869	$\frac{1}{2}(0^-)$
D_s^+, D_s^-	$c\bar{s}, \bar{c}s$	1968	$0(0^-)$
B^+, B^-	$u\bar{b}, \bar{u}b$	5279	$\frac{1}{2}(0^-)$
Λ_c^+	udc	2285	$0\left(\frac{1}{2}^+\right)$
$\Sigma^+, \Sigma^0, \Sigma^-$	uus, uds, dds	1189	$1\left(\frac{1}{2}^+\right)$
Ξ^0, Ξ^-	uss, dss	1315	$\frac{1}{2}\left(\frac{1}{2}^+\right)$
Ω^-	sss	1672	$0\left(\frac{3}{2}^-\right)$
Λ_b	udb	5624	$0\left(\frac{1}{2}^+\right)$